24/B

REPORT

OF THE

ROTHAMSTED EXPERIMENTAL STATION

FOR

1957

WITH 50-YEAR INDEX
(1908–57)

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COMMONWEALTH MYCOLOGICAL INSTITUTE
3 JUL 1958

Rothamsted Experimental Station
Harpenden, Herts.

LAWES AGRICULTURAL TRUST

REPORT

for

1957

(WITH 50-YEAR INDEX, 1908–57)

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1958

THE ROTHAMSTED LABORATORIES FOR SOIL AND PLANT NUTRITION, ERECTED 1914–1915.

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C. P. Burnham, B.A.(Cantab.)
B. Clayden, B.Sc.(Sheffield)
C. B. Crampton, B.Sc.(Bristol)
A. Crompton, B.Sc.(Leeds)
D. C. Findlay, B.A.(Cantab.)
R. D. Green, M.Sc.(Lond.)
B. R. Hall, B.Sc.(For.)(Edin.)
C. A. H. Hodge, B.Sc.(Wales)
J. M. Hodgson, B.Sc.(Lond.)
R. A. Jarvis, B.Sc.(Dunelm.)
D. W. King, B.Sc.(Lond.), A.R.I.C.
D. Mackney, B.Sc.(Bristol)
C. C. Rudeforth, B.Sc.(Lond.)
R. S. Seale, M.A.(Cantab.)
A. J. Thomasson, B.A.(Bristol)
J. P. Watson, M.A., B.Sc.(Oxon.)

Colonial Pool of Soil Surveyors

A. O. Ballantyne, Ph.D.(Edin.) (In Northern Rhodesia)
J. C. Chisnall, B.Sc.(Nott.) (In Sierra Leone)
G. F. M. Murdoch, M.A.(Edin.) (In Swaziland)
J. Stark, B.Sc.(Glas.) (In British Guiana)

Chemists

C. L. Bascomb, B.Sc.(Agric.)(Reading)
Audrey M. Du Feu, B.Sc.(Lond.)
H. H. Le Riche, B.Sc.(Lond.)

Temporary Workers

J. Loveday, M.Agric.Sci.(Adelaide)
R. R. Storrier, B.Sc.(Agric.)(Sydney)

Cartographer

D. V. Jones

Assistant Staff

Pamela Ash, R. Ball, Mrs. Audrey M. Denton-Hughes, Mrs. Joan K. Foster, Sylvia B. Reeves, Mrs. Beryl J. T. Sims, E. M. Thomson, Mary R. White, M. J. Wilson

Woburn Experimental Station

Director

Sir William G. Ogg, M.A., B.Sc., LL.D.(Aberd.), Ph.D. (Cantab.)

Officer in Charge

C. A. Thorold, M.A.(Oxon.), A.I.C.T.A.

Chemist

T. W. Barnes, M.Sc.(Lond.), F.R.I.C.

Assistant

G. Pearce

FARM STAFF

Head of Farms

J. R. Moffatt, B.Sc.(Agric.)(Lond.), N.D.A., A.I.B.A.E.

Assistant

G. F. Cole

Bailiff

A. W. Neill

Farm Workers

C. Hathaway, W. Hummerston, H. Millard, K. Parsonage, W. Wilson

Imperial College of Science and Technology

(Research Institute of Plant Physiology)

Director

F. G. Gregory, D.Sc.(Lond.), F.R.S.

Head of Department

F. J. Richards, D.Sc.(Birm.), F.R.S.

Scientific Staff

W. W. Schwabe, D.Sc.(Lond.)
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U. Pethiyagoda, B.Sc.(Ceylon)
S. Nachmony, M.Sc.(Jerusalem)

Assistant Staff

W. S. Biggs, Priscilla M. Dutton, C. Sinclair, Pamela J. Smith

The Commonwealth Bureau of Soils

Director	G. V. Jacks, M.A.
Consultant Director ...	Sir W. G. Ogg, M.A., Ph.D., LL.D.
Assistant Director ...	W. D. Brind, B.Sc.(Agric.)
Assistants	G. A. Greenwood, B.Sc. Mrs. M. Kathleen Milne, B.Sc. T. Z. Nowakowski, Ph.D. I. Szladits, Ph.D. Norah J. Watts, M.A.
Indexer	Mrs. Sophie Adams
Clerks	Christine E. Dollimore, Mrs. Iris Lindsay, Marguerita D. Payne, Mrs. Rita M. Starkins

The Bureau is one of ten Commonwealth Agricultural Bureaux, and was established at Rothamsted in 1929. Administratively and financially the Bureau is distinct from the Station, but the closest collaboration exists in the work of the two. The Director of the Station is Consultant Director of the Soil Bureau.

The function of the Bureau is to assist workers in soil science throughout the Commonwealth by providing technical information, by promoting contact between them and by rendering any technical assistance possible when they are in this country. A bi-monthly abstract journal *Soils and Fertilizers*, covering the literature of soil science, fertilizers and the culture of field crops throughout the world, is published, together with occasional monographs—*Technical Communications*—on subjects of general interest. To facilitate its work, the Bureau seeks to be well informed as to the personnel engaged in soil work in the Commonwealth and the problems on which they are engaged. Each Government nominates one of its staff as Official Correspondent to the Bureau, who acts as liaison officer in Bureau matters and assists in the collection and distribution of information. The issue of technical information is usually free to all workers in soil science who ask the assistance of the Bureau.

PREFACE

The Rothamsted Experimental Station was founded in 1843 by the late Sir J. B. Lawes, with whom was associated Sir J. H. Gilbert for a period of nearly sixty years. Lawes died in 1900, and Gilbert in 1901; they were succeeded by Sir A. D. Hall from 1902 to 1912, and by Sir E. J. Russell from 1912 to 1943, when the present Director, Sir William G. Ogg, was appointed.

For many years the work was maintained entirely at the expense of Sir J. B. Lawes, at first by direct payment, and from 1889 onwards out of the income derived from the endowment fund of £100,000 given by him to the Lawes Agricultural Trust. In 1904 the Society for Extending the Rothamsted Experiments was instituted for the purpose of providing funds for expansion. In 1906 Mr. J. F. Mason built the Bacteriological Laboratory; in 1907 the Goldsmiths' Company generously provided a further endowment of £10,000, the income from which—since augmented by the Company—is devoted to the investigation of the soil. In 1911 the Development Commissioners made their first grant to the Station. Since then, Government grants have been made annually, and at the present time over 90 per cent of the necessary funds is provided from Government sources—mainly by the Ministry of Agriculture and the Agricultural Research Council.

The main block of laboratories was opened in 1919; another block was erected in 1924 for plant pathology by a grant provided by the Ministry of Agriculture out of the Development Fund; and Red Gables, the house adjoining the laboratories on the north side, was converted into an Administration Building to hold the Commonwealth Soil Bureau, Staff Common Room and Conference Room.

Since 1945 Rivers Lodge, a house belonging to the Station, on the south side of the laboratories, has been used to provide accommodation for the Statistical Department. In 1946 Rothamsted Lodge, the dower house of the Estate, was purchased and occupied by the Entomology and Bee Research Department.

In 1947 the plant nematology work under Dr. T. Goodey, of the Institute of Parasitology, was transferred to Rothamsted, and a new laboratory was erected to house this department.

Large glasshouses, including special insect-proof houses for virus studies, were added in 1926, 1928 and 1931 by aid of generous grants from the Rockefeller Foundation, the Empire Marketing Board and the Ministry of Agriculture. A new large range of houses, some of which are insect-proof, was erected in 1935 for plant-pathology investigations.

In 1940 the south wing was completed and the old chemical laboratories reconstructed. These extensions and reconstructions provide accommodation for the Chemistry, Biochemistry, Physics and Microbiology Departments; in addition, a range of pot-culture houses was built. In 1939 a laboratory was completed for workers from the Imperial College of Science and Technology. A West

Building, to house the Entomology and Insecticides Departments together with the mycologists of the Plant Pathology Department, was completed in 1955.

The Rothamsted Home Farm of 250 acres came under the management of Sir John Lawes in 1834, the experimental fields being worked from the farm buildings at the Manor House. In 1913 the first range of farm buildings and cottages was erected on the site of the present buildings. These were considerably enlarged in 1930–32 and equipped for electric light and power; further additions were made in 1939–40. A range of six farm cottages was erected in Ninnings Field in 1948, and a concrete road constructed from the back of the laboratories to the farm.

The non-experimental part of the farm was reorganized in 1928 to meet the prevailing economic conditions, much of the land being laid down to permanent grass, and cattle and sheep were introduced. In 1939 this policy was reversed, ley farming was introduced and the arable acreage was increased to meet wartime conditions.

The extension of the experiments to various outside centres in Great Britain, begun in 1921, has proved so advantageous that it has been developed. Not only is useful information spread among farmers, but Rothamsted also gains considerably by this closer association with the universities and Advisory Services. As part of this extension, the Station took over in 1926 the Woburn Experimental Farm. We were thus able to make experiments simultaneously on the light land at Woburn and the heavy land at Rothamsted.

In May 1934 the negotiations for the purchase of the farm and some adjoining parts of the Rothamsted estate were completed. Thus the Lawes Agricultural Trust owned the site of the laboratories, the experimental and ordinary farm fields, Knott Wood, the Manor House and grounds, the farm manager's house and eight cottages, the total area being 527 acres. The purchase price was £35,000, all of which was raised by public subscription. Generous contributions were received from Sir Robert McDougall and others, and a highly encouraging feature of the appeal was the number of subscriptions received from farmers, village school teachers and from oversea sources.

In 1955 the two fields Delafield and Whittlocks, adjoining the western boundary of the estate and amounting to 26 acres, were bought by the Lawes Agricultural Trust; in 1956 Baldwin's Paddock and Lodge, comprising about 6 acres near Hatching Green, were also bought, together with Geescroft Wilderness (3 acres) and Road Piece (a strip of about 16 acres running along Redbourn Lane).

During 1951–52 the Manor House was converted into a Hall of Residence, providing accommodation for seven families, rooms for twenty single workers and two guest rooms. Some of the large public rooms are available for lectures and general institutional purposes. The fabric of the older part of the building, part of which dates back to the 13th century, has been carefully preserved. The greater part of the cost was met by the Ministry of Agriculture, but the Station also received encouragement and financial aid from the Pilgrim Trust. The conversion has greatly enhanced the amenities of Rothamsted, and the accommodation is particularly useful for the younger members of staff and temporary workers from overseas.

An illustrated guide to the Manor with an account of its history has been published (1953) under the title *The Manor of Rothamsted*.

The activities of Rothamsted are not confined to the British Isles, but are gradually reaching out to many parts of the world. The Station regularly participates in work for the solution of agricultural problems of great importance to the Commonwealth.

Rothamsted offers research facilities for post-graduate students, but unfortunately the number of additional workers that can be accommodated is at present strictly limited by lack of laboratory space.

The Commonwealth Bureau of Soils, one of the ten Commonwealth Agricultural Bureaux set up to act as clearing centres of information on agricultural science, has been located at Rothamsted since its establishment in 1929.

The Library

For many years after the foundation of Rothamsted Experimental Station in 1843 its Library consisted almost entirely of the books assembled by Sir John Lawes. A rapid expansion began in 1913, when the collection of Sir J. H. Gilbert was presented to Rothamsted by his widow. In 1917 the Library contained some 10,000 volumes. Gifts, grants from a number of individuals and societies, exchange and purchase have increased its scope, until it now contains:

	(Approximately)
Periodicals ... ... (Current, about 1,600)	5,000
Books, 1841–	12,000
Books, 1471–1840 ... ... (including 14 incunabula)	3,500
Bound volumes of pamphlets	400
MSS.	100
Maps	300
Prints (excluding those in books and journals) ...	300

—in all about 18,000 items, comprising some 56,000 volumes.

The yearly accessions of books and periodicals, bought and exchanged, amount to approximately 1,100 volumes.

The chief periodicals on agriculture and related subjects published throughout the world are received, either by subscription or in exchange, and constitute the most-used section of the Library.

The stock of books also covers a wide range of subjects—not only agriculture but also, e.g., chemistry, physics, biology, botany, geology, zoology, meteorology and statistics. The books are arranged according to the Universal Decimal Classification system. The collection of early printed books (1471–1840), which is kept separate from the rest, includes fourteen incunabula, amongst which is a copy of the first dated edition of Pier de' Crescenzi's *Ruralium commodorum libri duodecim*—the earliest printed book on agriculture —produced at Augsburg by Johann Schüssler in 1471 (Hain 5828). The collection of MSS. includes a copy of the *Treatise of Husbandry*, by Walter of Henley (fl. 1250), written in England on vellum about the middle of the 14th century.

The prints, which are mainly of the 18th and early 19th centuries, include portraits of eminent agriculturists, bucolic scenes, and representations of livestock. A most valuable addition to this collection was made in 1948, when Lord Northbrook presented to Rothamsted his father's collection of prints. A detailed catalogue of Rothamsted's livestock prints is now published.

The Library is designed to meet the requirements of the staff of Rothamsted; but its use may be extended to any research worker who can show his need of it.

The General Catalogue of the Library is kept on cards. There is also a published catalogue of the collection of early printed books on agriculture (Rothamsted, 1926; second edition, 1940; supplement, 1949). A complete catalogue of the serial publications in the Library was published in 1954.

The *Quarterly bulletin of the International Association of Agricultural Librarians and Documentalists* is edited and published in the Library.

INTRODUCTION

By the Director

This is the fiftieth year for which the Rothamsted Annual Report has been published. A summary index covering this period has been included in this issue.

By the death of Sir John Simonsen on 20 February 1957 the Lawes Agricultural Trust Committee lost a valued member. He was appointed to the Committee in 1950 and had been Treasurer since 1952. He has been succeeded on the Trust Committee by Dr. L. E. Sutton and as Treasurer by Professor A. Robertson.

It is with deep regret that we record the death in June 1957 of Lord Clinton, who over a long period of years rendered great service to Rothamsted. He was Chairman of the Lawes Agricultural Trust Committee from 1925 to 1937 and a Trustee from 1929 until his death. He has been succeeded as a Trustee by the Marquess of Salisbury.

We also record with regret the death of Mr. C. T. Gimingham, a former director of the Ministry of Agriculture Plant Pathology Laboratory; he was on the Rothamsted staff from 1905 to 1907 and from 1923 to 1928.

Three members of the staff who have given long and devoted service to Rothamsted retired at the end of September: Dr. H. G. Thornton, who had been head of the Soil Microbiology Department since 1920; Dr. Katherine Warington, who joined the Botany Department in 1921 and did pioneer work on trace elements; and Miss M. M. Browne, a member of the staff of the Plant Pathology Department since 1927, who was awarded the M.B.E. in the New Year's Honours list. Dr. P. S. Nutman was appointed head of the Soil Microbiology Department, of which he has been a member since 1939.

Sir William Ogg was elected a Corresponding Member of the All-Union Academy of Agricultural Sciences of the U.S.S.R., and at the invitation of the Academy visited Moscow to attend the Anniversary Session and receive his scroll of membership. Other visitors to the U.S.S.R. were Dr. P. W. Arnold and Dr. J. L. Monteith, who spent a month there under an exchange arrangement, and Dr. R. Greene-Kelly, who is working in the Faculty of Geology and Soil Science of the University of Moscow for nine months under an exchange scheme between the Academy of Sciences of the U.S.S.R. and the Royal Society.

Dr. J. M. Bremner was awarded a Rockefeller Foundation Fellowship and is dividing a year between Iowa State College and the University of Illinois. Dr. E. W. Buxton visited the University of California and research institutes in the U.S.A. with a Kellogg Foundation Fellowship. The National Research Council of Canada awarded a post-doctorate Research Fellowship to Dr. Gillian N. Thorne, enabling her to work in the Science Service Laboratories in Ottawa for a year; and Mr. H. D. Patterson accepted a Visiting

Professorship at the Institute of Statistics, University of North Carolina. Mr. R. H. Kenten and Mr. A. J. Arnold have been seconded to the West African Cocoa Research Institute, Ghana, and Mr. G. V. Dyke to Hunting Technical Services to work on a land improvement scheme in Iraq.

Mr. F. C. Bawden attended meetings of the Advisory Committee for Agricultural Research in the Sudan, and Dr. F. Yates visited the Indian Statistical Institute and the Indian Council of Agricultural Research. Mr. F. G. W. Jones took part in a nematology " Seminar-Workshop " held at the Agricultural Experiment Station, Knoxville, Tennessee, and visited research centres in Alabama and Florida. He also attended meetings in Munster as Advisory Editor of *Nematologica* and as a member of the Governing Board of the Society of European Nematologists. Dr. H. Greene, Adviser on Tropical Soils, visited Malta, Pakistan and several East African territories. Mr. D. H. Boalch attended meetings of the Executive Committee of the International Association of Agricultural Librarians and Documentalists in Paris, and Dr. K. Mellanby went to Amsterdam for the first editorial meeting of *Entomologica experimentalis et applicata*. Dr. G. W. Cooke visited laboratories in Holland and France for discussions on phosphate fertilizers; Dr. A. Muir and Dr. D. A. Osmond took part in the F.A.O. Working Party on Soils at Bonn. Dr. P. W. Murphy, a member of the Zoology Committee of the International Society of Soil Science, visited Geneva for discussions on the organization of the International Colloquium on Research Methods in Soil Zoology to be held at Rothamsted in July 1958.

Sir William Ogg attended the International Potash Congress in Vienna. At the invitation of the Royal Society Dr. H. L. Penman was a delegate to the Pacific Science Congress in Thailand. Mr. F. C. Bawden took part in the International Congress on Poliomyelitis in Geneva and in Symposia on Viruses and Virus Diseases in New York and Madison. Mr. N. W. Pirie attended conferences on " Cellular biology, nucleic acids and viruses " organized by the New York Academy of Sciences and the Poliomyelitis Foundation. He also took part in a conference on " The origin of life on the earth " arranged by the Academy of Sciences, Moscow, and the International Union of Biochemistry. Mr. M. V. Tracey accepted the invitation of the U.S. Navy to a symposium on " Marine Biology " in Seattle. Dr. J. B. Free attended the Congress of the International Union for the Study of Social Insects and Dr. O. Talibudeen the UNESCO International Conference on Radioisotopes in Scientific Research, both held in Paris. Rothamsted sent delegates to the 16th International Congress of Pure and Applied Chemistry in Paris, the 4th International Nematology Symposium in Hamburg, the 4th International Congress of Crop Protection in Hamburg, the 30th Session of the International Statistical Institute in Stockholm, the 3rd International Conference on Potato Virus Diseases at Wageningen and meetings of the International Institute of Sugar Beet Research.

Visitors

Visitors to the Station included Lord Hailsham, Lord President of the Council; Mr. W. M. Seivwright, Minister of Agriculture, Jamaica; Mr. S. P. Le Roux, Minister of Agriculture, Union of South Africa; Mr. L. R. Abavona, Minister of Agriculture, Ghana; Mr. L. Korbut, Embassy of the U.S.S.R.; Dr. Corcinschi, Roumanian Minister in London. Among scientific visitors were Professor N. J. Thomas, of Ontario Agricultural College; Dr. L. D. Baver, Director of the Experiment Station of Hawaiian Sugar Planters' Association; Professor Belina of Warsaw University; Professor Litynski of Cracow University; Professor Imshenetsky, Director of the Institute of Microbiology of the Academy of Sciences of the U.S.S.R.; Professor Lazarenko of Lvov University with a party of clay mineralogists; delegations of Russian drainage experts and agricultural engineers. Three Russian scientists, Professor F. E. Kolyasev of the Agro-physical Institute of Leningrad; Mr. D. A. Korenkov of the All-Union Research Institute of Fertilizers and Soil Science, Moscow, and Mr. G. S. Muromtsev of the All-Union Research Institute of Microbiology, Moscow, stayed at Rothamsted for a month on an exchange basis.

The Work of the Station

In the **Physics** Department much attention is being given to clays. Studies of water uptake suggest that the slaking action of water on dry clays or clay soils is caused by rapid swelling of the clay, entrapped air being a rare and very minor contributory factor. Slow uptake of water, from a humid atmosphere, for instance, permits gradual swelling with time for readjustment of the clay structure, and such material remains coherent when flooded; whereas dry clay wetted quickly will disrupt. In field conditions, as one would expect, water vapour diffuses downwards ahead of the liquid wetting front, so confining the slaking action to a thin surface layer. Further studies of the electrical charges on kaolin have led to the suggestion that the charge distribution may be such that large electrical stresses are set up at the edges of the kaolin crystals, causing crumbling to a debris that greatly affects the physico-chemical behaviour of the clay.

Crop environment (microclimate) work has been concentrated on spring wheat; a new technical development is a balance that gives a continuous measure of transpiration or condensation. The records obtained show that short-period fluctuations in the rate of water uptake by the wheat follow very closely the changes in sunshine intensity. The irrigation experiment at Woburn showed good crop responses to watering in the dry spring and early summer of 1957, the yield of beans—a new test crop in this experiment—being doubled by 4 inches of irrigation between April and July. The first few cuts of grass showed a benefit, but from mid-July onwards there was adequate rain for all crops.

The results of a ploughing experiment started at outside centres in 1944 have been published. On average, over a range of loam soils, deep ploughing (to about 14 inches) increased potato yields

by about ½ ton/acre as compared with shallow ploughing (to about 8 inches). On organic soils, deep ploughing decreased yields.

Several series of field experiments testing fertilizers carried out by the **Chemistry** Department were concluded in 1957 and are being summarized. Experiments during the past three years emphasize the large seasonal variations in the returns from nitrogen fertilizers; for wheat and potatoes in 1956 and 1957 only half as much nitrogen was necessary for maximum profit as in 1955. Over the same period there has been no advantage from the common practice of splitting the nitrogen dressing for winter wheat. Applying the whole dressing in spring has been as satisfactory as applying part when sowing and the remainder as a top-dressing in spring. Experiments with calcium nitrate have shown that heavy dressings damaged germination and early growth of all crops under conditions where an equivalent amount of ammonium sulphate was harmless. Similar damage was reported last year from the use of urea containing an appreciable amount of biuret. Neither material is used to any extent in this country at present, but their use may increase, and these drawbacks require thorough investigation. Experiments on vegetables have not shown greater yields from concentrated organic nitrogen fertilizers as compared with ammonium sulphate, which is much cheaper.

Experiments on phosphate fertilizers have shown that none of the materials tested is superior to superphosphate. Dicalcium phosphate dihydrate gives as good yields for many crops and on many kinds of soil, but as produced at present its physical condition —a dusty powder—is unsatisfactory.

Processes involving the use of nitric acid to attack rock phosphate or the ammoniation of superphosphate are possibilities in the future, but generally the products contain dicalcium phosphate, which, in granulated form, tends to be slow-acting. A nitrophosphate made on pilot plant scale proved to be much inferior to fertilizers based on superphosphate. An ammoniated compound fertilizer which had half of its phosphate in water-soluble form was more promising, the phosphorus it contained proving nearly as satisfactory as that in superphosphate. Experiments with Gafsa rock phosphate showed it to be of little value for grass on acid soils but much more useful for kale and swedes. There was no advantage from grinding it more finely than is specified in our Fertilizer Regulations.

Progress has been made in using a radio-isotope of phosphorus to investigate the way in which soils supply phosphate to crops. Appreciable amounts of soil nitrogen may be fixed by clay minerals, and in some subsoils half of all the nitrogen present was found to be combined in this way. Further progress has been made in elucidating the nature of the soil nitrogen combined with organic matter. Field investigations at both Rothamsted and Woburn show that ammonium salts are converted to nitrate much more slowly than was supposed. Average summer rainfall did not wash nitrate out of the surface layers, but it was leached out during prolonged wet weather. Rapidly growing grass quickly removed all nitrate or ammonium supplied by quite heavy fertilizer dressings. Laboratory work on the mats which often form on permanent pasture, particularly on marginal and hill land, show that these are

associated with acid conditions and deficiency in bases. Besides mechanical treatment, adequate liming is essential to bring about their decomposition.

In the **Pedology** Department the determination of clay minerals in soils and rocks forms an important contribution to the work of the Soil Survey by assisting with soil correlation and classification. Among soils from abroad that have been examined, some from Somaliland contain an uncommon clay mineral (palygorskite) similar to that widely found in soils from the Middle East and derived from rocks of similar age. An unusual mineral (jarosite) has been found associated with peaty soils in Romney Marsh and with soils derived in part from Oxford clay. It is a basic sulphate of iron and potassium, and probably comes from the sulphides formed in the peat or existing in the clay. In connection with the study of the mechanism of aggregate formation in soils, an investigation of the micro-structures of clay powders has shown that with montmorillonite, a swelling clay, the surface area is very sensitive to small additions of water, although the aggregates have considerable rigidity at low water contents. Further work has been done on the mineral beidellite; in this the new electron microscope, with the aid of which it is possible to measure platelets down to 10 μ thick, is proving invaluable.

In the study of trace elements of the Lower Lias clays, associated with the disease known as " teart " in stock, a correlation has been found between the heavy metals (e.g., molybdenum, copper, etc.) and organic matter and also to some extent with carbonate content. In South Wales most of the Lias clays have a low molybdenum content, which fits in with the apparent absence of " teart " in that area. The trace element content of soil on Broadbalk field at Rothamsted is remarkably uniform, considering the varied and long-continued manurial treatments. As might be expected, the unmanured plot in general shows the lowest contents of the various metals.

In the study of aqueous leaf extracts, further work has been done on the nature of compounds which are active in mobilizing iron and other elements in soils.

The current programme of the **Soil Microbiology** Department deals with two main topics, the ecology of soil micro-organisms and various aspects of the nitrogen cycle. Because it bears upon the practical question of assessing the contribution of the free-living nitrogen fixers to the nitrogen resources of the soil, a study has been made of the distribution of Azotobacter in certain soils. This has revealed differences due to seasonal influence as well as to cropping and manurial treatment. Investigations on symbiotic nitrogen fixation have been continued. These include selection and breeding work on strains of red clover which are defective in the power of fixing nitrogen. Studies on the initial infection of clover roots by nodule bacteria include an examination of the relation of the primary pattern of root-hair infection to actual nodule formation. All soils in which legumes have been grown for more than one season develop a bacteriophage active against the nodule organism, and a study is being made of the relationship between bacteria and phage in an attempt to ascertain what may be happening in soil to change the properties of nodule bacteria.

The inhibition of germination of fungal spores by certain aerobic spore-forming bacteria has been demonstrated in all soils examined except those with very acid reaction. This has an important bearing on the control of soil-borne diseases. Germination of some fungi is completely inhibited; in other cases chlamydospores form immediately after germination. The inhibiting action disappears in the close proximity of growing roots; this action of root exudates is being investigated. Further work on the bacterial decomposition of herbicides in soil is in progress.

Earlier work in the **Botany** Department has shown that variations in yield of crops are brought about mainly by changes in leaf area and that changes in the photosynthetic efficiency of the leaves (net assimilation rate) are relatively much less important. More attention is therefore being given to investigating factors that affect leaf growth, an aspect of plant physiology that has been neglected. A study is being made of the changes brought about by nitrogen, phosphorus and potassium in the leaf area per plant by affecting the rate of production, expansion and length of life of leaves. Gibberellic acid sprayed on potato leaves increased their size without much affecting their photosynthetic activity, and so in a short period increased yield; but it caused deformations of the tubers. Reduction in yield in a sugar-beet plot which had insufficient soil moisture was accounted for almost wholly by reduced leaf growth. There were indications in the same experiment that irrigation water applied in small amounts gave slightly greater increases in yield than the same amount given at one watering. An experiment on barley confirmed previous work on kale and sugar beet in showing that there is not much, if any, scope for increase of yield by increasing leaf area at the time it is high; increased dry-matter yield depends, therefore, on extending the period of high leaf area, but the grain yield of cereals depends on photosynthesis in the ears as well as in the leaves. Striking confirmation has been obtained of the fact that it is the upper leaves of a crop that do most of the photosynthesis.

From the weed-control studies there is further evidence that, under temporary ley, the population of wild oats decreases only slowly after a rapid fall in the first year or two. Stubble burning stimulated germination of wild oat seeds at or near the surface, but most of the seeds in the soil were not affected. Further work has been done on the physiological effect of virus infection.

In the **Biochemistry** Department the location and state of enzymes in the leaf are being investigated in subcellular fractions damaged as little as possible by the extraction process. In previous work the ribonuclease and phosphatase associated with microsomes have been studied, but attention is now being given to the larger or mitochondrial fraction of the cell, since it is known that the oxidation mechanisms of many other tissues are associated with this fraction. Many difficulties have been encountered in making mitochondrial preparations from leaves in anything like a pure state, but their oxidizing properties have been demonstrated. The processes that convert latent into active enzymes are also being studied. The phenol oxidase of broad-bean leaves is activated by exposure to acids, alkalis and detergents. An understanding of the conditions

necessary for activation of this enzyme may shed light on other enzyme activations and on the manner in which variations in the protein content of a leaf is reflected in its enzymic composition. Further work has been done on the thiaminase of bracken, and amine oxidase is being tested with more complex substrates in order to make alkaloids with more complex structures than those made hitherto. Previous experience with the catalytically active metals and oxidative enzymes is now being applied to a study of the factors controlling blackening in potatoes. Work on the enzymic and possibly non-enzymic processes leading to loss of infectivity by fragmented portions of tobacco mosaic virus continues, and also the work on chitinase and other enzymes in connection with the study of soil organic matter. Progress has been made in isolating the hatching factor of the potato-root eelworm. The technique for extracting leaf protein has been improved and the product, which is now nearly tasteless, can be given a wide range of flavours to make it acceptable as human food. Pig and chicken feeding experiments in other institutes show that it has the nutritive value expected from its amino acid composition.

Further progress was made in the **Plant Pathology** Department in finding treatments to free vegetatively propagated plants from viruses; a preliminary trial with a clone of King Edward potatoes, rendered virus-free by treatment, indicated that this may yield better than commercial clones. The mild winter and spring led to unusually early and heavy aphid infestations, and in consequence virus diseases were extremely prevalent. In previous years, spraying potatoes with DDT has proved adequate to control leaf roll, but this year aphids were on the plants as soon as they emerged, and it is unlikely that spraying will have been so beneficial. Because of the early infestation of beet crops, warnings were issued to farmers and over 100,000 acres were sprayed against aphids. Where spraying with " Metasystox " (applied at high or low volume) was timely, virus yellows was checked and increases in yield of roots up to $4\frac{1}{2}$ tons/acre were obtained; but where spraying was delayed until aphid infestation was established, it gave no benefit. Breeding against yellows shows promise. Inbred lines of beet previously selected for their resistance to yellows out-yielded commercial lines by more than 25 per cent in places where yellows was severe. Of the four cereal viruses being studied, barley yellows dwarf was exceedingly prevalent. It infects many grasses, is transmitted by several aphid species and occurs in strains of different virulence, as does ryegrass mosaic virus, which is transmitted by eriophyid mites and also infects many grasses. Weather studies and other work on apple scab caused by the fungus *Venturia inaequalis* was continued in an attempt to improve the forecasting and prevention of outbreaks. This disease is now better controlled in the Wisbech area than previously, though fewer sprays are applied. Further studies on eyespot and take-all confirmed the importance of preceding crops on the incidence of these cereal diseases. Wheat, barley and oats, but particularly wheat, yielded better on land which had carried potatoes or beans the previous year. Take-all was unusually severe on Broadbalk, especially where lime had been applied to plots that were previously acid. Attempts to prevent pea wilt by treating

infested fields with fungicides only delayed the onset of the disease, and resistant varieties seem to offer the only method of control. Even these may be only temporarily effective, because the fungus readily produces new forms able to infect previously resistant plants.

In the **Nematology** Department work continues on eelworm species of economic importance. Investigations have recently been started on migratory nematodes that move about in the soil, feeding on roots with or without actually penetrating into them. Some species are widespread in permanent grassland and in various cultivated crops, and their occurrence may have to be taken into account in considering crop sequences and rotations. A beginning has also been made in the study of the pea-root eelworm with experiments to determine the effect of different levels of infestation on the growth of peas, field beans and broad beans. Further work has been done on cereal-root eelworm and cabbage-root eelworm. Irradiation of infested mushroom compost has shown that heavy dosage rates of gamma rays are required to kill the nematodes, many of which are harmful in mushroom production. A number of small soil-inhabiting insects and allied animals have been found which feed on nematodes, especially on the white immature females of the cyst-forming kinds. An attempt is being made to find out what part these predators play in limiting field populations of nematodes injurious to crops. Much attention continues to be given to the potato-root eelworm. Experiments on the effect of nematicides on the cysts have shown that hatching tests designed to assess the kill obtained must be continued until hatching ceases if reliable results are to be obtained; it is not sufficient to judge the effect of nematicidal treatment by tests run for short, fixed times. During the year the potato-root eelworm has been successfully cultured on tomato roots in sterile root culture, and it is hoped that this will help in the elucidation of the reproductive cycle of the eelworm and enable advances to be made on problems connected with its physiology. This may also throw light on the races of the eelworm which can break the resistance of crosses between cultivated potato varieties and wild potatoes from the Andes. A high proportion of field populations contain resistance-breaking forms, and these increase each time that resistant potato hybrids are grown. The wild potato, *Solanum vernei*, proved more or less resistant to all populations of eelworm against which it was tried.

In the **Insecticides** Department further research has been done into the effect of organophosphorus compounds on the esterases present in insects and into the various factors, such as temperature, which affect the toxicity of insecticides. The study of the pyrethrins has also been continued and a chemical method evolved for the preparation of Pyrethrin I and Pyrethrin II in pure form from pyrethrum extract in sufficient quantities for large-scale experimental work. The fact that the relative toxicity of the four active constituents of pyrethrum appears to differ with the species of test insect makes the assessment of their relative value as insecticides difficult.

On fungicides, the effect of temperature on the toxicity of mercury salts to fungus spores is being investigated.

Further field experiments have confirmed that one correctly

timed spraying with a systemic insecticide can control bean aphid and give large increases in yield of spring beans in years when aphid attack is severe. In work on the effect of chemical control on the natural enemies of the bean aphis it was shown that in early June when insecticides were applied predators were uncommon, and that the spraying did not upset the natural control by predators in July and August. Low and high volume applications were equally satisfactory in the case of systemic insecticides; with contact insecticides high volume appeared to be more effective. In collaboration with the Plant Pathology Department, further work was done on the chemical control of the vectors of potato viruses. The search for improved chemical methods of controlling wheat-bulb fly has continued. No consistently effective spraying method has been found, and for seed treatment nothing that has been tested is more satisfactory than dieldrin and heptachlor. Dieldrin, either drilled with the seed or applied at a high rate as a seed dressing, has so far proved the most effective control measure, but the cost is considerable. Laboratory experiments showed that chlorinated hydrocarbon insecticides, such as dieldrin, applied as seed dressings, are taken up by the seedling wheat plant and have an important systemic action; in work on the relative importance of contact and systemic action of seed dressings it was shown that the former may be relatively unimportant unless the seed is sown close to the soil surface.

Although most insect and farm pests can be controlled by insecticides and fungicides, there is no cure for slug attack on a farm scale, and the **Entomology** Department has re-started work on the subject. The life cycle of the various species, and methods of estimating populations more accurately on a field-scale, are being studied. New work has also been begun on the ecology and biology of the frit fly, which in recent years has done considerable damage on Rothamsted farm.

Some progress has been made with the investigation of the effects of climate on the metabolism and behaviour of insects. Many larvae, even those found in the soil, may suffer from dehydration, and the upset in water balance renders them less able to survive exposure to unfavourable temperatures. Some species of insect are much more cold-hardy than others, and there is considerable variation within the same species, depending apparently on the conditions under which they have been reared; it appears that there is no direct relationship between the properties of their tissue fats and ability to withstand high or low temperatures. So far, we cannot foretell accurately how winter temperatures will affect survival of insect pests, but acclimatization plays an important part. Further detailed studies have been made on the wheat-bulb fly, both in the field and the laboratory, and on insect populations. The latter have dealt particularly with the establishment and growth of aphid populations under various conditions, and with the importance of parasites, predators and attendant ants. Work on gall midges continues. The importance of these pests and the value of the service given by the department in this connection is demonstrated by the fact that in the first three months of 1957 over a hundred inquiries, from twenty-two countries, were received on this subject. Some progress has been made with the study of

forest soils, particularly in determining the rate of disappearance of leaf litter from the forest floor and on the biology of mites found in these types of soil. Although much work has been done on earthworms, there is still much to be learned about the part they play in maintaining or improving soil fertility, and further studies are being carried out on worm populations in marginal land and in orchards where insecticides and fungicides may drastically reduce the soil fauna.

Direct experimental evidence has been obtained by the **Bee** Department that "queen substance", which the worker bees lick from the body of their queen, plays a very important role in controlling colony behaviour. An ethanol extract of this substance, prepared from queens and fed in distilled water to a group of queenless worker bees, caused them to behave as though they possessed a queen. Drifting or wandering of bees from one colony to another can result in the transmission of disease, and if extensive, can nullify records of honey production and breeding programmes based on them. Attempts to prevent this undesirable phenomenon have shown that much more attention should be paid to the directions in which the hives are facing than to their colours. Drifting is reduced to a minimum by arranging the hives in irregular formation, painting them different colours and, above all, facing them in different directions.

The importance of weather conditions and nectar flow in determining the incidence of both Nosema and Acarine diseases has been demonstrated, good nectar flows being correlated with marked reductions of Acarine infection. It has been shown that the death of a colony from this disease in winter is unlikely to occur unless 70–80 per cent of its members are infected in the previous autumn. Further attempts are being made to find a practical means of controlling European Foul Brood. Work on swarming behaviour has shown that brood rearing, swarming and honey storage do not, as has been widely believed by beekeepers, form a sequence in the summer cycle of behaviour of honeybee colonies; all show a similar distribution throughout the season. Other subjects investigated include the size of the apertures in wire gauze through which bees can feed one another—important in introducing queens in cages—and the efficacy of some of the simple methods for extracting wax from old combs.

In the **Statistics** Department the electronic computer has continued to give reliable service and has enabled much more work to be handled, the results dealt with being double and the actual analyses treble the numbers dealt with in 1956. A Pye magnetic-tape transport store unit presented by the National Research Development Corporation is being linked up with the machine. Several long-term experiments have been statistically analysed, including the six-course rotation experiments at Rothamsted and Woburn, the Woburn ley–arable experiment and experiments comparing the fertilizer responses of crops grown with and without farmyard manure. Close collaboration has been continued with the National Agricultural Advisory Service on the design and analysis of crop and animal experiments, and assistance given to them and to other bodies, including the Agricultural Research

Council Statistics Group at Cambridge, in the summarization of experimental data.

The Survey of Fertilizer Practice, carried out in conjunction with the National Agricultural Advisory Service, was considerably extended in 1957 with the co-operation of the Fertiliser Manufacturers' Association, forty-five counties or part counties being surveyed. The analysis of the data was carried out, for the first time, on the electronic computer, which has considerably speeded up the preparation of the reports. Assistance is being given in a national survey of the diseases of dairy cows which has been undertaken by the Ministry of Agriculture, Fisheries and Food, and in various other surveys of animal diseases and fertility. There has also been co-operation with the National Institute of Agricultural Engineering, the National Vegetable Research Station, the Pest Infestation Laboratory, the Milk Marketing Board and other organizations.

The number of experimental plots dealt with by the **Field Experiments** Section and **Farm** staffs has more than doubled in the last 10 years, and now stands at about 3,400 full-scale plots and a large number of microplots. With this expanding programme the provision of suitable sites for experiments will shortly become a problem. On the Rothamsted estate, after deducting woodlands, allotments, roads and unsuitable portions of fields, the area available for experiments amounts to just over 300 acres. About 65 acres are taken up by the classical and other long-term experiments, leaving about 250 acres, of which only 85 are suitable for critical experiments on phosphorus and potassium.

The season was remarkable for the absence of winter frosts, resulting in the worst seedbeds for many years; a drought followed, and the spring-sown crops had a bad start. They made a good recovery, however, and yields were only slightly below average. Broadbalk was harvested by combine harvester for the first time; the straw was baled and weighed. The plots of the Agdell rotation experiment were again manured with nitrogen only and cropped with potatoes to study residual effects from the long-period mineral treatments. Similar work on residuals from an old classical experiment was carried out on the Exhaustion Land, where six different crops were grown instead of the usual barley crop. The deep ploughing experiment has been stopped after two complete six-course rotations, and the results have been summarized. Ploughing to a depth of 12 inches (compared with 6 inches) has not been very successful in Rothamsted soil. Its most consistent effect has been on sugar beet, where the increase has averaged 2·9 cwt. sugar/acre or 6 per cent of the mean yield. The average effect on potatoes and wheat over the 12-year period has been negligible. The after effects of deep ploughing on barley, oats and hay (which had normal depth of ploughing) were also negligible. The interactions of deep ploughing with various manurial treatments have also been examined. For sugar beet there was no advantage from ploughing-in dung to 12 inches depth; the dung gave a rather bigger return when ploughed-in to the shallower depth. Phosphate and potash did better when ploughed-in than when harrowed into the seedbed. For potatoes, fertilizers gave better results applied in the ridges than ploughed-in.

At Woburn the permanent wheat and barley areas are again being cropped following a period of fallow, during which the land has been limed to correct acidity. The occurrence of potato-root eelworm has necessitated the substitution of sugar beet for potatoes as the first test crop in the ley–arable experiment. In the same experimental area, lucerne-stem eelworm has been found, and certain plots have had to be ploughed up as a control measure. Some of the infested land is being used by the Nematology Department for experimental purposes.

PHYSICS DEPARTMENT

H. L. Penman

There have been changes in the established staff. W. W. Emerson left in May to join the Soils Division of the Commonwealth Scientific and Industrial Research Organization of Australia, and D. A. Pearce left in August. Dr. J. A. Currie joined the department in April, and Pearce was replaced by G. Szeicz in November.

Of the temporary workers, Dr. R. L. Davidson returned to South Africa in August, and Mr. H. D. Orchiston arrived from New Zealand in August. Among short-period workers, come and gone, we were happy to welcome Professor F. E. Kolyasev, of the Agro-physical Institute of Leningrad, who spent a month with us. In addition, Mr. G. Prillevitz of Wageningen used the department as a base for studies of irrigation activity in England.

G. H. Cashen took part in a two-day discussion meeting in Louvain, Belgium; P. F. Noble visited research laboratories in Holland and Germany; and, on an exchange basis, J. L. Monteith spent a month in laboratories in Leningrad and Moscow. H. L. Penman attended the Pacific Science Congress in Thailand.

During the year the degree of M.Sc. (London) was awarded to I. R. Cowan (former temporary worker) and Miss Margaret Dettmann.

Soil Physics

Soil cultivation

Two sets of experiments were started by E. W. Russell (now Director, East African Agriculture and Forestry Research Organization). The first of these, of simple design, compared deep and shallow ploughing, with and without subsoiling, mainly for potatoes on a number of commercial farms. Dr. Russell has now published an account of these experiments, and an abstract of his paper is on p. 262. As a supplement to this abstract, the paper contains the following: ". . . on the average, deep ploughing by itself, compared with shallow ploughing, puts up the yield of potatoes by about half a ton on the clays and loams, but puts down the yield on the organic soils, whilst subsoiling the shallow ploughed plots puts up the yield on the clays and perhaps on the sands, and subsoiling the deep ploughed plots appears to reduce the yield on the loams but to increase it on the light loams."

The second experiment, on our own farm, was more complex, involving six crops, and cultivation/fertilizer interactions. This has now completed its second rotation and come to an end. A statistical summary of the results has been prepared, and it is hoped that an interpretive analysis of the data will not be too long delayed.

Electrical charges on clay (G. H. Cashen)

The work on the electrical charges on kaolin has been continued using the technique in which the fall in pH of kaolin suspensions is measured as increasing amounts of cetyl trimethyl ammonium bromide (CTAB) are added. Previous results had shown that there was a lower limit to the net negative charge, and that with a deflocculant such as oxalate present a higher negative charge was measured, independent of pH, indicating that the planar charges had been isolated. If the difference between these two charges is taken as a measure of the maximum positive edge charge, the problem is to account for the presence and the amount of hydrogen ion on the planar faces necessary to develop the edge charge and give the marked fall in pH as the CTAB is added. The kaolin had been purified by washing with N-KCl, 10^{-3} N-HCl solution to remove any exchangeable aluminium or free aluminium compounds, and the planar charge should be almost completely satisfied by potassium ions prior to removal of excess electrolyte and washing of the kaolin with distilled water to get it chloride free. At this stage there should be little exchange acidity. This suggests that the kaolin crystals become unstable on washing because of the positive edge charges: equivalent amounts of the counter ions—chloride and potassium—must be washed away, and their removal will leave the crystal in a state of electrical stress. It is well known that clays which have been washed with acid are transformed to mixed hydrogen aluminium clays on ageing, and the decomposition of the lattice to give aluminium in the exchange complex would be more easily explained if the positive charges on the edges were originally due to a loss of hydroxyl by the crystal edge, rather than to proton transfer. If it were proton transfer, then the stress could be relieved by a migration of protons within the crystal: if it is a loss of hydroxyl the stress could be relieved—in theory—either by ionization of water with hydroxyl groups discharging the edges and hydrogen ions occupying the sites of the lost cations; or by a decomposition of the crystal equivalent to stripping off the charged edge and giving hydrogen ions or complex aluminium ions in the exchange complex. If this concept is correct it may help to explain the deflocculation of kaolin by neutralization or destruction of the positive edge charge, as addition of alkali, for example, could be regarded as a neutralization of acidity, which might otherwise have given rise to positive edge charges by exchange.

The decrease in cation exchange capacity on heating kaolin to 300° C. (R. Greene-Kelly (1955), *J. phys. Chem.* **59**, 1151) has been confirmed, but apparently kaolin differs from montmorillonite in that the decrease is limited to an amount approximately equal to the positive edge charge, whereas for lithium montmorillonite the cation exchange capacity may be almost wholly eliminated. Another feature for kaolin is that a similar decrease is obtained for the sodium kaolin, and as Na^+ is too large to fit into the octahedral spaces it seems that the effect is independent of the size of the exchangeable cation. If the reduction in base exchange capacity is caused by entry of a cation into the lattice, then these phenomena would be explained if the penetrating ions were protons, equivalent in amount to the positive edge charge.

Soil structure

Organic matter in soil (W. W. Emerson)

With Dr. Emerson gone (and not yet replaced), and Miss Dettmann's departure imminent, there may be a check to the impetus of this work. Emerson had already given a broad survey of his work (*Rep. Rothamst. exp. Sta. for* **1956**), and since then has published a preliminary note on the stereo-chemistry of organo-clay complexes in which organic compounds are taken up between the basal surfaces of montmorillonite and halloysite to form interlamellar complexes. Considering simple alcohols, he suggests that the orientation of the carbon chain is perpendicular to the 001 plane—and not parallel to it as originally assumed. By invoking a hydrogen bond between an oxygen atom of the alcohol and an oxygen atom of the clay surface, and putting in the best available estimates of bond lengths and directions, he has obtained good agreement between calculated spacing and that measured by X-ray analysis. Emerson's work goes on, and it is hoped that Commonwealth Scientific and Industrial Research Organization reports from the Soils Division, Adelaide, South Australia, will take over as these Rothamsted reports come to an end.

Sodium saturation technique (W. W. Emerson and M. Dettmann)

The modified technique (*Rep. Rothamst. exp. Sta. for* **1956**), though simplified, remains very tedious in application. It has been applied to soils from Rothamsted, Jealott's Hill and Bayfordbury for testing purposes, and to a Woburn experiment operationally. In the first group the interpretation of the results is largely a reflexion of field experience and intuition, but it is satisfying to find that the technique does put soils in an expected order of stability, i.e., the soil from old grassland is more stable than the same soil after arable cropping. The test on the ley–arable experiment at Woburn showed that stability was greater on the ley plots than on the arable plots, and both were better than the uncropped and frequently cultivated headlands.

Cross comparisons between soils of different texture cannot yet be made, and our own use of the technique is limited to estimating the effects of management on the structural stability of a given soil. Even here some control of acidity may be necessary, but experiments on buffering near pH 7 are not yet conclusive. The work done so far reveals that acid soil crumbs have a greater cohesion than similar calcareous crumbs, for two reasons. (i) In acid crumbs there is an additional attractive force between the positively charged edges and negatively charged faces of the clay crystals, revealed by a reduction in cohesion when the soil is brought to pH 7. (ii) Exchangeable trivalent ions increase the attractive force between clay crystals, for Fe^{+++} and Al^{+++} have been extracted from such soils, with a reduction in cohesion; and on adding these ions to a sodium clay the treated material remains stable in distilled water, whereas the untreated clay disperses in 0·02*N*-NaCl.

From this and other evidence it appears that liming an acid soil *decreases* the cohesion of the aggregates, and it may be that the known beneficial effect of liming lies in promotion of micro-bio-

logical activity, and in the maintenance of a sufficiently high concentration of Ca^{++} in the soil water to ensure re-flocculation of dispersed clay, so keeping drainage waters clear.

Water uptake by clays and clay soil (M. Dettmann)

Detailed time-and-motion studies on the wetting of clays suggest that if (depending on the clay mineral) the crystal lattice is allowed to take up one or two monolayers of water slowly, then subsequent flooding does not produce the shattering effect (slaking) that it has on a dry clay. The explosive effect of entrapped air seems to be very slight, and in our experiments has only been diagnosed in field crumbs of very low stability. The time needed to form the monolayer(s) appears to be of the order of about 10 minutes in a saturated atmosphere, and it may be that the slaking action of rain on dry field soil is limited to the surface, because water vapour can diffuse downward ahead of the liquid wetting front, so permitting an orderly controlled swelling of the clay, without disruption.

Measurements of such controlled swelling on pure sodium clays have shown that in *N*-NaCl (equivalent to 97 per cent relative humidity) montmorillonite expands to twice its original thickness, an increase which is consistent with the acquisition of three monolayers of water between each pair of unit crystal sheets, an effective area of 800 $m.^2g.^{-1}$, and available X-ray evidence on lattice spacing in this state. For an illite (usually considered as having a non-expanding lattice) the swelling is 33 per cent.

Optical study of thin sections of field soils in polarized light has shown small patches of oriented clay around sand grains, and others randomly distributed in the general matrix. Rapid wetting could lead to rapid swelling along preferred lines, so causing breakdown. Slow wetting could leave time for local relative motion of particles to take up the strains, so preventing disruption at the expense of some dislocation.

Soil structure field experiment (W. W. Emerson and J. A. Currie)

The first block, ploughed up in 1953–54, had carried three test crops of spring beans, wheat and barley, and a new cycle was started in spring 1957 with a simplified arrangement in which the effect of ryegrass and lucerne will be compared with the effect of fallow. Both crops were cut for hay, and, in effect, provided fourth test cropping. The lucerne on the plots which were formerly cut for hay (1949–53) showed considerable differences in growth, that on the former lucerne plot being very good, that on the former ryegrass plot being markedly inferior. In contrast, the growth was much more uniform on plots on which grazing had been simulated.

On the second block, carrying barley as its third test crop, plants on the former fallow plots were less vigorous than those on former grass plots, being shorter, thinner stemmed and paler green in the early stages of growth. Though the differences became less noticeable as the season progressed, they persisted to harvest and in yield corresponded to about 5 cwt./acre.

The third block, ploughed up in 1955, carried its second test crop, the first, in 1956, being half beetroot and half carrots. Red beet and carrots were again grown on half plots where carrots and beet

had been the year before. A month after germination, the former grass plots were markedly better in appearance than the former fallow plots, with larger though slightly fewer plants, but the differences in appearance became less apparent during the summer, and at harvest the mean weight per carrot was about the same, so that the former fallow plots gave a slightly greater total yield. For the beet, the main difference in response was the production of an extra 2 tons/acre on the former " grazed " plots as compared with the former hay plots.

From the present evidence it seems that such structural changes as we are able to produce are important at the time of germination and during the early stages of growth, and this aspect of the problem is to be examined a little more closely.

Soil aeration (J. A. Currie)

Experiments have started on a field method for measuring gaseous diffusion into and within a soil. Progress in the preliminary laboratory work has been encouraging.

Agricultural Meteorology

Micro-meteorology (I. F. Long)

All the available micro-meteorological equipment was concentrated in a single crop of spring wheat to permit a better study of the fine detail, and it is hoped that current analysis will answer a few of the questions posed by the 1955 and 1956 results. As before, the temperature and humidity gradients were measured at six levels and the wind at four levels in and above the crop, the telescopic mast again being used to allow constant observation heights above the growing crop. In addition to the anemometers, the " slow-response hot-bulb anemometer ", constructed during 1956, was installed in the crop to give an idea of crop ventilation, and has functioned satisfactorily throughout the growing season. The " dew-point-gradient recorder " was also installed to give the general picture of water-vapour movement, and measurements of soil temperature at surface and 10-cm. depths, along with leaf temperatures at two levels, were continuously recorded.

The third set of equipment was used for short-period experiments, which were as follows: (*a*) Measurements at constant level on a line north–south across the experimental plot, at intervals of 7 m. Air flow was measured at crop height, or at 1 m. above ground; temperature and humidity were measured at crop height, or at 35 cm., or at 10 cm. above ground. (*b*) Vertical profiles in fine detail in and above the crop.

Good progress is being made with the analysis of the records, and some interesting results are emerging. For example, it seems clear that dew formation frequently occurs, but it does not always persist until 9 hours G.M.T., when the routine weather observations are taken. As many dew nights may be missed as are recognized. An *ad hoc* experiment to influence condensation (and evaporation) by electrostatic charge was tried, using metal plates at 300 volts above and below earth potential. The experiment was unsuccessful.

Comparison of leaf temperatures shows that the smaller narrower

leaves of wheat do not heat up so much as potato leaves during the day, and the night cooling, though of the same order, is slightly less.

Heat and water balance (J. L. Monteith)

From April–August 1957 a continuous record was obtained of the evaporation from a crop of spring wheat using a large recording balance. Designed by Mr. L. G. Morris, the machine was built under his direction at the National Institute of Agricultural Engineering and has been installed in Great Field II, near the meteorological enclosure. Beneath the pan of soil in which the crop is grown and which has an area of 56 × 56 inches and a depth of 25 inches, crossed strips of beryllium–copper provide a robust suspension free from hysteresis and deformation. The "balanced" position is obtained by altering a fixed load at the end of a counterweight arm, and when evaporation, or rainfall, or condensation causes a change in soil-pan weight an electric motor moves a riding weight until equilibrium is restored. A pen attached to the rider records its position on a clock drum, so producing a graph of weight against time on which 1 cm. represents an evaporation of 0·3 mm. water. For dew studies, the rider weight can be decreased to give a sensitivity of 0·04 mm. condensation per cm. scale.

From the time of sowing at the end of March until harvesting in mid-August, evaporation was about 29 cm. and rainfall 17 cm., the hot dry weather of early summer being responsible for an unusually high soil-moisture deficit. Preliminary analysis of the records suggests that at times the recorded evaporation rate may have been higher than that in the surrounding crop because of the inadequacy of guard plants round the perimeter of the balance. After allowing for this effect, it appears that transpiration, and evaporation from the standard open water tank, were of the same order during active growth with a maximum rate of about 5 mm./day in early June. Transpiration was so closely controlled by available radiant energy that sunny and cloudy periods during a day could easily be picked out from inspection of the weight record. Hour-by-hour measurements of evaporation are being correlated with net radiation measured with a ventilated Gier and Dunkle radiometer and with the temperature and humidity profiles obtained by Long.

Condensation on mustard grown after harvesting the wheat reached 0·2–0·3 mm. on several nights in late September and in October. These amounts are greater than those previously observed with very short grass (maximum 0·13 mm. per night), but are still insignificant compared with evaporation over periods of two or three days.

Radiometry (J. L. Monteith)

Commercial instruments for measuring solar radiation are too big and too heavy for work inside crops, so a small, simple and inexpensive thermopile solarimeter has been designed and built. It has a linear response, and sufficient output to operate a portable galvanometer, but the design must be improved to eliminate an unacceptable dependence on solar azimuth.

On a cloudy day (when azimuth error was negligible) little variation was found between the reflexion coefficients of different green crops: sugar beet 26 per cent; kale 27 per cent; potatoes 27 per cent; lush grass 5–10 cm. high 27 per cent; cut grass in meteorological enclosure 30 per cent; dry bare soil 19 per cent. Short-wave radiation intensity in a mature stand of wheat was found to decrease exponentially below the top of the crop. With some knowledge of the transmission factor of the leaves, this attenuation might be used to give values of Leaf Area Index without destructive sampling of the crop.

An attempt has been made to establish correction factors for the Rothamsted radiation records obtained with a Callendar receiver and recorder between 1923 and 1954, this being one of the longest available British records. Penman's broad survey of the correlation between radiation and duration of sunshine has been extended to find correlations for each month of the year. Analysis is still in progress, but it appears that for some months the best empirical estimate of solar radiation is the long-term average for the month.

Heat flow in soil (P. F. Noble)

Continuous records of temperature variations down to a depth of 40 cm. in heavy clay soil have been obtained for several periods when the diurnal variation in amplitude of the surface temperature closely resembled a sine wave. Most of these records have been obtained under conditions of artificial heating, but some very satisfactory data have been obtained under natural heating in the early summer. Preliminary analysis of these records has been made, and in spite of considerable variations in moisture content, particularly in the surface layers, the same general pattern of thermal constants exhibiting marked discontinuities between 15–20 cm. has been shown in nearly all data analysed.

Unfortunately the flux plates which were placed in the soil at the same depths as the thermometers broke down, due to moisture absorption, and no records are available for the periods in which temperature records were satisfactory for analysis.

Soil water (I. F. Long and P. F. Noble)

A neutron ratemeter monitor has been built, based on the Harwell monitor type 1262 C but with some modifications in the power supply and ratemeter circuits. For electrical calibration and checking, auxiliary electronic equipment has been built, including a pulse generator.

A polonium–beryllium source is used, and laboratory calibrations of the system as a moisture meter indicate that it may be possible to use the equipment with source and detector lying on the soil surface, at least on the irrigation experiment. Field checks will be made in the coming year.

Irrigation at Woburn (H. L. Penman, T. W. Barnes and P. F. Noble)

There has been a change in cropping with the start of a new rotation. Beans replaced the potatoes (forbidden because of eelworm infestation), and spring wheat replaced the barley. Sugar beet—in the rotation—and grass remain as before. The bean experiment

was made a simple 2 × 2 treatment with irrigation and spraying against black fly as variables, half plots being dunged. On the grass, nitrogen dressings were doubled so that the new lower dressing is the same as the old upper dressing, and on some of the plots an attempt has been made to do a nitrogen balance based on soil and plant analyses.

The weather of 1957 was much the same as that of 1956, a dry spring and early summer leading into a wetter period so that the irrigation season was effectively ended by mid-July. The grass and beans responded very markedly to the early watering, and the differences in the final yields are a reflexion of this better early growth. Early growth of the wheat was similarly affected, but the difference in appearance became less marked as the crop aged, and the final difference in yield is only partly a direct effect of irrigation, for some of the control plots, one severely and two mildly, were attacked by fungus. The table gives responses to full irrigation designed to keep the plots near field capacity (C plots) at two levels of nitrogen dressing (N1 and N2) for three of the crops. For the beans neither spraying nor dunging had any measurable effect, and only the general means are given.

Woburn Irrigation, 1957

Crop	Period	Rain, inches	Irrigation, inches	Plot	Yield, cwt./acre	
Grass	1 Apr.–27 Sept.	12·6	—	ON_2	63	Dry matter 8 cuts
				ON_4	85	
		12·6	5·4	CN_2	82	
				CN_4	102	
Sugar beet	1 May–27 Sept.	12·4	—	ON_1	59·9	Sugar
				ON_2	63·6	
		12·4	3·6	CN_1	59·3	
				CN_2	60·1	
Spring wheat	1 Apr.–5 Aug.	6·4	—	ON_1	25·4	Grain
				ON_2	25·8	
		6·4	3·2	CN_1	28·0	
				CN_2	33·0	
Beans	1 Apr.–19 Aug.	9·1	—	O	15	Grain
		9·1	4·0	C	30	

During the irrigation season changes in soil moisture were determined by regular sampling on O and C plots of the grass. In addition, gypsum blocks and porous-pot tensiometers were used, and while the latter behaved fairly well, the gypsum blocks changed their calibration after being some months in the soil.

Miscellany

I. F. Long has designed and built metering equipment for assessing the humidity and temperature of the forced-air draught of the farm grain dryer.

H. L. Penman has about half-finished writing a survey of the role of vegetation in hydrology, and nearly finished a revision of the evaporation map of the British Isles.

CHEMISTRY DEPARTMENT

G. W. Cooke

W. B. Haines retired in September. K. Shaw resigned at the end of the year to take up an appointment with the National Agricultural Advisory Service. B. Harrington emigrated to Australia in October. Mrs. Mary P. Webster joined the staff in January and left in September. D. S. Jenkinson was appointed to the staff in October to work on soil organic matter and Miss Barbara M. Close to take charge of glasshouse experiments.

P. W. Arnold returned in August from a period of secondment to the West African Cocoa Research Institute. S. G. Heintze spent a year's leave of absence at the Galloway Laboratory, Hamilton, New Zealand.

J. M. Bremner was awarded a Rockefeller Foundation Fellowship tenable at Iowa State College and at the University of Illinois. P. W. Arnold spent a month in the U.S.S.R. as a member of an agricultural delegation invited by the Soviet Union Ministry of Agriculture. He visited the All-Union Research Institute for Fertilizers and Agro-Soil Science, as well as a number of other research institutes in Moscow. G. W. Cooke visited laboratories and experimental stations in Holland and France to discuss phosphate fertilizers. O. Talibudeen attended the International Conference on the Peaceful Uses of Atomic Energy organized by UNESCO and held in Paris in September.

P. W. W. Daborn of the Forestry Commission was seconded for a further year's work on nutrition problems in forest nurseries. Two members of the Colonial Agricultural Research Service were trained in soil fertility work and field experimentation: R. Webster left in September to take up an appointment in Northern Rhodesia, J. W. O. Jeffery joined the Department in October.

Professor S. W. Melsted of the University of Illinois worked in the Department until May while on sabbatic leave. Miss A. Stojkowska (from Yugoslavia), Mr. P. Arambarri (from Spain), Dr. S. N. Chakravarti (from India) and Dr. J. Rodriguez (from Spain) all joined the department as temporary workers during the year. Mr. L. Overrein (from Norway) worked here for several weeks during the summer.

Nitrogen Fertilizers

Times and rates of application for winter wheat (F. V. Widdowson)

A three-year series of field experiments on winter wheat which tested different rates of " Nitro-Chalk " applied as spring top-dressings is summarized in Table 1. In 1955 the rates of application were 52 and 104 lb. N/acre; in both 1956 and 1957 69 and 139 lb. N/acre were given. Tests were also made of splitting the lower rate and applying one-third of the dressing at sowing-time in autumn. Three varieties were compared in each experiment: Hybrid 46,

Minister and Heine 7. They behaved rather similarly in any one year, except that Minister tended to give higher yields than the other varieties when no nitrogen was applied and also that this variety was rather less responsive than the others. On average,

TABLE 1

The effect of different rates and times of application on yield and nitrogen content of winter wheat (averaging the results of three varieties and of all experiments in each year)

	1955	1956	1957
No. of experiments	3	4	4
	Yield of grain, cwt./acre		
Yield without nitrogen	25·4	21·6	28·9
Increase in yield from N fertilizer			
From low rate...	8·2	7·0	4·6
From high *over* low rate	3·3	1·1	0·4
Gain from splitting low rate... ...	0·5	−0·3	−0·2
	Per cent of N in grain		
Without nitrogen	1·57	2·02	1·87
Increase from N fertilizer			
From low rate...	0·05	0·17	0·16
From high *over* low rate	0·22	0·22	0·25

the low rate of nitrogen increased yields by over 30 per cent in 1955 and 1956, but in 1957 average yields were only increased by 16 per cent. The extra yield from the second dose of nitrogen gave a good return in 1955, but in the two later years this higher rate of dressing was unprofitable. There was no worthwhile gain from giving a portion of the nitrogen when sowing in autumn. The average percentage of nitrogen in the grain varied greatly from year to year, but in any one year all varieties tended to give rather similar values. The second dose of nitrogen gave a larger average increase in the nitrogen content of the grain than the first dose.

Forms of nitrogen fertilizers (F. V. Widdowson, A. Penny, R. J. B. Williams and G. W. Cooke)

Experiments on spring cereals compared ammonium sulphate and a Continental fertilizer grade of " calcium nitrate " (actually a double salt of calcium nitrate and ammonium nitrate). The results of three years' work are summarized in Table 2. Both fertilizers were tested when combine-drilled and when broadcast on the seed-bed at sowing-time. The low and high rates of ammonium sulphate combine-drilled increased yields of barley by about 30 and 40 per cent respectively, and the extra gain from the second level over the first level of manuring was profitable. In comparison with this well-marked general effect of nitrogen the differences between yields given by the two forms, and by the two methods of application, tended to be small. Where ammonium sulphate was applied by combine-drill consistently higher yields were obtained than by broadcasting (this confirmed the results of earlier work: *Rep. Rothamst. exp. Sta. for* **1956**, p. 44). When calcium nitrate was applied there was no consistent gain from combine-drilling. When the fertilizers were combine-drilled ammonium sulphate gave higher

yields than calcium nitrate, but when they were broadcast the nitrate was best. (Calcium nitrate drilled with the seed at the higher rate checked germination and early growth; although the crops grew away from the check, it may have been responsible for a small

TABLE 2

The effects of two forms of nitrogen fertilizer applied in two ways on yields of spring barley and spring wheat (yields of grain in cwt./acre are stated after averaging all experiments on each crop)

	Barley (7 experiments)		Wheat (5 experiments)	
	Combine-drilled	Broadcast	Combine-drilled	Broadcast
Yield without nitrogen ...	25·7		25·7	
Increase from 34 *lb. N/acre*				
As ammonium sulphate ...	7·6	5·9	2·8	3·1
As calcium nitrate	6·7	6·1	2·0	3·1
Increase from 68 *lb. N/acre*				
As ammonium sulphate ...	10·5	9·8	3·6	4·4
As calcium nitrate	10·1	10·6	3·5	4·6

loss of yield.) Wheat was much less responsive than barley, the low and high dressings of ammonium sulphate giving average increases in yield of 12 and 16 per cent respectively, and the extra gain in yield from the double as compared with single dressing barely paid for the fertilizer. Broadcasting the fertilizers on the seedbed gave higher average yields of wheat than drilling them with the seed; there were no consistent differences between the effects of nitrate and ammonium. The percentage of nitrogen in barley grain was increased by nitrogen fertilizer, and the form of the nitrogen and the way it was applied had little effect. The increases in nitrogen contents of wheat grain caused by fertilizers were rather smaller.

Potatoes. The results of three years' work (summarized in Table 3) emphasize that, for the restricted area covered by these experiments, there were marked seasonal effects on the general profitability of nitrogen. At present-day support-prices for potatoes the highest rate of dressing (1·5 cwt. N/acre) was justified in the 1955 experiments; but in 1956 and 1957 dressings higher than 0·5 cwt. N/acre were unprofitable on average. In each year calcium nitrate gave lower yields of potatoes than ammonium sulphate at all rates of dressing, nitrate tending to be markedly inferior at the high rate. Poor results obtained with calcium nitrate were partly due to damage to emergence and early growth; this effect was most marked in experiments where the fertilizers were broadcast over furrows prepared for planting which concentrated them near to the seed. At centres where the fertilizers were broadcast on flat land before planting by machine, nitrate did not cause a visible check to early growth and average yields given by calcium nitrate were only a little less than those given by ammonium sulphate. The urea used in the 1956 experiments was a granulated fertilizer grade material imported from the Continent. It contained over 4 per cent of biuret; this material damaged establishment and early

growth in all the experiments where it was spread over furrows prepared for planting, but even where fertilizer and soil were mixed before planting by machine the high rate of urea gave poor yields. In 1957 a pure form of chemical-grade urea was used containing little biuret; it caused a slight amount of damage where fertilizers were placed close to the seed, but it gave average yields similar to those given by ammonium sulphate.

TABLE 3

Yields of potatoes and kale (in tons/acre) given by three nitrogen fertilizers

	1955		1956			1957		
	Ammonium sulphate	Calcium nitrate	Ammonium sulphate	Calcium nitrate	Urea	Ammonium sulphate	Calcium nitrate	Urea
POTATOES	(7 experiments)		(8 experiments)			(7 experiments)		
Yields without nitrogen	7·2		10·4			8·9		
Increases in yield from:								
0·5 cwt. N/acre ...	1·3	1·2	1·1	1·0	0·8	0·5	0·4	0·7
1·0 cwt. N/acre ...	2·1	2·0	1·2	1·0	0·5	0·5	0·4	0·5
1·5 cwt. N/acre ...	2·5	1·4	1·3	0·4	−0·4	0·5	0·3	0·6
KALE	(2 experiments in each year)							
Yields without nitrogen	16·3		9·4			19·0		
Increases in yield from:								
1·0 cwt. N/acre * ...	3·8	4·2	11·6	9·3	8·1	5·9	3·7	5·5
2·0 cwt. N/acre * ...	5·3	5·5	11·4	12·4	9·0	6·6	2·2	6·1
High rate, half early, half late	6·9	6·1	13·6	11·7	11·2	7·0	6·2	6·9

* 0·6 and 1·2 cwt. N/acre in 1955 only.

Kale. The average results of six kale experiments are stated in Table 3. In 1955 and 1956 calcium nitrate and ammonium sulphate gave similar increases in yields of kale, but in 1957 calcium nitrate was inferior, particularly at the high rate of application. Inferior results from calcium nitrate were associated in each year with damage to germination which often occurred when the heavy dressing of this fertilizer was used. At some centres sufficient plants were established to give a satisfactory crop, but at other centres germination was damaged so seriously that yields were reduced. The urea used in 1956 had a high biuret content, and it damaged establishment seriously and reduced yields. The purer material used in 1957 caused slight damage to establishment, but was not as dangerous as calcium nitrate, and it gave satisfactory yields. The kale experiments also tested split dressings, half of the heavy dressing being applied in the form listed in Table 3 before sowing, and half as a dressing of " Nitro-Chalk " in July. Divided dressings gave slightly higher yields than dressings applied wholly before sowing.

Concentrated organic nitrogen fertilizers for vegetables (R. G. Warren and G. W. Cooke)

A series of field experiments carried out over 12 years on vegetable crops to compare organic fertilizers with ammonium sulphate has now been summarized. For the crops grown crushed hoof and formalized casein (a waste product of the plastics industry) were roughly as effective as an equivalent amount of nitrogen as ammonium sulphate, the " organics " tending to be slightly inferior for

rapidly growing crops with a heavy nitrogen requirement (such as cabbage, tomatoes and potatoes) and slightly superior for crops (such as leeks, lettuce and onions), which required only small dressings of nitrogen in these experiments. Crushed hoof and formalized casein gave similar yields of most crops. There were no marked gains from treating hoof with formalin; a coarse (5–7 mm.) sample of formalized casein did not give materially different yields from the ordinary (2 mm.) product. Individual batches of processed leather wastes were tested in too few experiments to provide reliable average yields; the better batches behaved in much the same way as crushed hoof. Dried blood was tested in a few experiments, and there was no reason to suggest that it behaved very differently from ammonium sulphate or hoof. In one experiment the plots were treated continuously with nitrogen fertilizers for 10 years and were then cropped with grass for 3 more years without further manuring. The " residual effects " of unformalized hoof and of finely divided formalized casein were not larger than the " residual effects " of ammonium sulphate. Coarse formalized casein had much the same residual effect as the fine material; residues of formalized hoof gave slightly larger yields than did residues of untreated hoof. The extra yields of grass given by all nitrogen fertilizers after dressings had ceased indicate simply the difference between fertility levels of soils which had received nitrogen manuring for 10 years and of soils which had received no nitrogen for that period. The soil of unmanured plots lost about 6 per cent of its total nitrogen during the 10-year period, the nitrogen content was maintained at its original level on plots receiving hoof, formalized casein or ammonium sulphate dressings; there was a slight increase in soil nitrogen where formalized hoof had been applied for a number of years.

The experiments did not provide any clear and consistent indications that organic nitrogen fertilizers were either markedly superior or inferior to ammonium sulphate. For the crops grown the work gives no reason for using expensive organic fertilizers in preference to inorganic materials. Growers should work out correct methods of using cheap inorganic nitrogen for most kinds of vegetables grown in the open, and special attention should be given to the timing of the dressings. For glasshouse crops organic materials may have special merits where nitrate is quickly leached away by heavy watering, or where inorganic materials raise the salt content of the soil to dangerously high levels.

Formalized casein for grass (K. Shaw and F. V. Widdowson)

The experiment on Italian ryegrass laid down in 1956 (*Rep. Rothamst. exp. Sta. for* **1956**, p. 46) was continued in 1957. There was little benefit from formalized casein applied in March 1957 at the first two cuttings, and marked increases in yield were obtained from this material only at the fourth and final cutting. Dressings of ammonium sulphate repeated before each cut produced higher and more consistent increases in yield at each of the first three cuttings. Formalized casein applied in March 1956 produced considerable increases in yield at the first cutting in 1957. The experiment also tested calcium nitrate and urea, both products giving slightly higher aggregate yields than ammonium sulphate or casein.

Phosphate Fertilizers

Alternatives to superphosphate

A series of field experiments testing alternatives to superphosphate was initiated by the Fertilizer Conference of the Agricultural Research Council in 1951, when it appeared that supplies of sulphuric acid needed to make superphosphate would be restricted (*Rep. Rothamst. exp. Sta. for* **1953**, p. 40). Although the shortage of acid did not persist, field experiments were continued from 1954 to 1957 to provide further information on the agricultural value of phosphate fertilizers which are insoluble in water. Two series of experiments were carried out. Both series tested dicalcium phosphate, which is important because it supplies the bulk of the phosphate in fertilizers made by using nitric acid instead of sulphuric acid to attack rock phosphate, also because it is formed when superphosphate is ammoniated. The first series of experiments tested two other products as well: a nitrophosphate (made in England on pilot-plant scale by the process described by d'Leny (*Proc. Fertil. Soc.* 24 (1953)), and compound fertilizers made by ammoniating superphosphate or triple superphosphate. The second series of field experiments tested Gafsa rock phosphate ground to the customary fineness for direct application (approximately 90 per cent through the 100-mesh B.S. sieve) and a more finely ground material (70 per cent passing the 300-mesh sieve). Continental workers have suggested that rock phosphates ground so that most passes the 300-mesh sieve are much more active than the coarser materials generally used. In both series of experiments all plots received the same total quantities of nitrogen and potassium.

The field experiments were carried out by Advisory Soil Chemists of the National Agricultural Advisory Service, the Macaulay Institute for Soil Research, the East of Scotland College of Agriculture and the Northern Ireland Ministry of Agriculture. The work was organized and co-ordinated from Rothamsted by G. W. Cooke and F. V. Widdowson.

The results of the work are summarized in Tables 4 and 5 after subdividing the groups of experiments on most crops according to the pH values of the soils used. In both series the division into "acid" and "neutral" soils was made at pH 6·5. Superphosphate was tested at 0·3 and 0·6 cwt. P_2O_5/acre and the other materials at 0·45 cwt. P_2O_5/acre. (All dressings were applied on the basis of the *total* P_2O_5 content of the fertilizers.) Yields stated in Tables 4 and 5 for superphosphate supplying 0·45 cwt. P_2O_5/acre have been obtained by using the superphosphate response curve calculated for the appropriate group of experiments. Standard errors stated for the larger groups of experiments do not apply to yields obtained without phosphate fertilizer; they were calculated from the interaction between treatments and experimental centres. In experiments on barley (Table 4) the fertilizers were broadcast on the seedbed before sowing. Both dicalcium phosphate and ammoniated compound fertilizer gave average yields similar to those given by superphosphate, but nitrophosphate was inferior to the other materials tested. Nitrophosphate gave significantly smaller average yields of potatoes than superphosphate both on acid and on neutral

soils; dicalcium phosphate and ammoniated compound fertilizer were roughly equivalent to superphosphate. On average of the group of swede experiments on acid soils the other phosphates tested were significantly inferior to superphosphate, perhaps because water-soluble phosphate gave the crops a good start.

TABLE 4

Mean yields of barley, potatoes and swedes in experiments testing dicalcium phosphate, nitrophosphate and ammoniated compound fertilizer

	Barley	Potatoes		Swedes	
	All soils	Acid soils	Neutral soils	Acid soils	Neutral soils
No. of experiments	4	11	8	10	3
	Grain, cwt./acre	Tubers, ton/acre		Roots, ton/acre	
Without phosphate	22·8	7·0	9·9	9·4	10·2
With superphosphate supplying:					
0·3 cwt. P_2O_5/acre	26·1	8·6	11·6	14·0	18·2
0·45 * cwt. P_2O_5/acre ...	27·4	9·1	11·9	15·0	18·8
0·6 cwt. P_2O_5/acre	28·6	9·5	12·1	15·5	18·9
With 0·45 cwt. P_2O_5/acre as:					
Dicalcium phosphate ...	26·9	9·2	12·0	14·0	17·7
Nitrophosphate	25·3	8·6	11·1	13·3	18·3
Ammoniated compound ...	27·4	9·2	11·6	14·0	18·7
Standard error †	—	0·14	0·21	0·33	0·55

* Calculated from the average response curves.

† Standard errors do not apply to mean yields obtained without phosphate fertilizers.

The results of the second group of experiments are summarized in Table 5. For grass there were no significant differences between mean yields given by dicalcium phosphate and by superphosphate on average of the group of experiments on acid soils and also on average of the smaller group carried out on neutral soils. The average yields of grass given by Gafsa rock phosphate were only slightly greater than those obtained with no phosphate at all; on average of the experiments on acid soils both grindings of Gafsa rock phosphate were significantly inferior to superphosphate. For kale grown on acid soils all three phosphates tested gave average yields similar to those given by two-thirds as much phosphorus applied as superphosphate. On average of the large group of experiments on swedes on acid soils dicalcium phosphate was as effective as superphosphate; both rock phosphates gave lower yields than superphosphate at equivalent rate and for the coarsely ground material the difference was significant. The two grindings of Gafsa rock phosphate gave very similar yields of grass, kale and swedes and there were no significant differences between them. For the crops tested, these experiments provide no justification at all for the extra cost of grinding rock phosphate for direct application more finely than is customary in this country.

The 1954–57 series of co-operative experiments confirm earlier

work on alternatives to superphosphate. Although phosphate fertilizers which are insoluble in water may be as satisfactory as superphosphate for certain crops and on certain classes of soil, no water-insoluble phosphate has been consistently superior to it. Under adverse conditions, such as on acutely phosphate-deficient soils, or in dry and cold weather, the stimulus to rapid early growth

TABLE 5

Yields of grass, kale and swedes in experiments testing dicalcium phosphate and rock phosphate

	Grass		Kale		Swedes	
	Acid soils	Neutral soils	Acid soils	Neutral soil	Acid soils	Neutral soils
No. of experiments ...	18	6	6	1	16	3
	Dry matter, cwt./acre		Total crop, ton/acre		Roots, ton/acre	
Without phosphate ...	42·0	36·4	13·9	23·0	9·8	15·4
With superphosphate supplying:						
0·3 cwt. P_2O_5/acre ...	45·7	39·4	15·8	24·2	14·0	17·1
0·45 * cwt. P_2O_5/acre	46·9	39·9	16·1	25·3	15·0	17·3
0·6 cwt. P_2O_5/acre ...	47·8	40·1	16·3	26·3	15·5	17·4
With 0·45 cwt. P_2O_5/acre as:						
Dicalcium phosphate	46·4	39·2	15·7	25·0	15·0	16·8
Coarse Gafsa ...	43·4	37·0	15·5	24·1	14·3	16·8
Fine Gafsa	43·7	36·5	15·6	24·2	14·5	16·8
Standard error † ...	0·55	1·14	0·39	—	0·24	0·46

* Calculated from the average response curves.

† Standard errors do not apply to mean yields obtained without phosphate fertilizers.

which is provided by water-soluble phosphate may result in higher yields being obtained from superphosphate than from water-insoluble materials. Of the fertilizers tested in this last investigation dicalcium phosphate was roughly equivalent to water-soluble phosphate for barley, potatoes, grass and kale grown on all kinds of soil. Phosphate fertilizers made by nitric acid processes and by ammoniating superphosphate are believed to contain anhydrous dicalcium phosphate; it is quite possible that the anhydrous salt incorporated in a granulated fertilizer may not act as quickly as the finely divided dicalcium phosphate dihydrate which was used in this work. The British-made nitrophosphate tested in the 1954–57 experiments was clearly inferior to superphosphate for barley, potatoes and swedes. The material used contained one-third of its total phosphorus in water-soluble form, and 91 per cent was soluble in 2 per cent citric acid solution. The ammoniated compound fertilizer which was used in 2 of the 3 years had about half of its total phosphorus in water-soluble form, and it was practically completely soluble in citric acid solution; the phosphorus it contained was nearly as effective as that in superphosphate for barley and potatoes, but the material was a little inferior to superphosphate in one group of swede experiments. Gafsa rock phosphate is attractive because

it is a cheap fertilizer; it was rather less effective than an equivalent amount of P_2O_5 as superphosphate for both swedes and kale, but it was of very little value for grassland, even on acid soils. These statements on the value of alternatives to superphosphate are based on results obtained in the year of application, unfortunately the work provided no good evidence on the residual values of the tested phosphates. Where the experiments were continued for more than 1 year, second-year effects were generally small and difficult to measure precisely; this is particularly true of experiments on arable crops, where phosphate residues were diluted with soil by ploughing and cultivating before another crop was grown.

G. W. Cooke, G. E. G. Mattingly and F. V. Widdowson carried out field experiments at Rothamsted using radishes grown on very small plots to obtain further information on the rate of action of granulated fertilizers containing dicalcium phosphate. Superphosphate gave much higher yields of radish (harvested 4 weeks after sowing) than any of the granulated nitrophosphates tested. Residual effects were measured on grass which was sown immediately after harvesting the radishes; the effectiveness of the nitrophosphates increased rapidly, and for a second cut of grass taken 16 weeks after the experiment was started only one of the three nitrophosphates was significantly inferior to superphosphate. Radish were also used to compare granulated nitrophosphates with the fine powders made by grinding these materials; powdered nitrophosphates acted much more quickly than the granulated products from which they were made. Solubility of nitrophosphates in 2 per cent citric acid solution and in solutions of neutral ammonium citrate and alkaline ammonium citrate (all of these solutions are used for valuing fertilizers of this type in other countries) were of no use in assessing the values of the fertilizers tested in these experiments. The work has emphasized that granular nitrophosphates are at a serious disadvantage where very rapid action is needed for a crop with a short growing season, but that they are much more effective for long-season crops. There is no useful chemical method for providing a certain valuation of dicalcium phosphate in granular materials; conventional solubility tests may be satisfactory when powdered materials are used, but when granulated fertilizers are applied much must depend on the rate at which the granules break down and allow phosphate ions to diffuse away.

Combine-drilling of Potassium Fertilizers

(F. V. Widdowson, A. Penny and G. W. Cooke)

Twelve experiments on spring-sown barley which have been carried out during the last 3 years to compare combine-drilling and broadcasting of potash fertilizers are summarized in Table 6. Average responses to potash were large in 1955 and smaller in 1956 and 1957. In each of the 3 years combine-drilling muriate of potash gave higher average yields than broadcasting at both rates of dressing; the advantage of combine-drilling was large in 1955 and smaller in the 2 later years. In each year drilling the low rate (0·25 cwt. K_2O/acre) produced higher yields than broadcasting twice as

much potash. The gain from combine-drilling as compared with broadcasting 0·5 cwt. K_2O/acre averaged 2 cwt./acre of barley over the 3 years. The experiments were carried out in Hertfordshire and Bedfordshire on ordinary mineral soils chosen as being deficient

TABLE 6

The average effects of broadcasting and combine-drilling muriate of potash in experiments on barley

	1955	1956	1957	All years
No. of experiments	4	4	4	12
	Yields of barley grain in cwt./acre			
Mean yield without potash	25·8	30·8	23·8	26·8
Increase from 0·25 cwt. K_2O/acre:				
Broadcast	3·7	2·1	0·8	2·2
Combine-drilled	6·6	2·4	1·2	3·4
Increase from 0·5 cwt. K_2O/acre:				
Broadcast	4·6	1·8	0·3	2·2
Combine-drilled	7·3	3·6	1·6	4·2

in soluble potassium, and the work indicates that wherever potash fertilizers are justified for barley, they should be drilled with the seed to obtain the best returns from the dressing. Previous work has shown that there are very marked advantages from combine-drilling phosphate fertilizers for all cereals and that drilling ammonium sulphate with the seed gives higher yields than broadcasting this fertilizer. The practice of many farmers who drill a compound fertilizer with barley seed to supply all the nutrients needed by the crop appears to be well justified, and should lead to higher yields than broadcasting the same fertilizer before drilling.

MANURING OF CROPS

Flax (G. W. Cooke and R. G. Warren)

The results have been summarized of a series of 50 field experiments carried out during the War by Advisory Soil Chemists to examine the effects of manuring on total yields and quality of flax. The effects of fertilizers were small, on average of all similarly treated experiments the gains were:

	Yields in cwt./acre		
	Total crop	Green-scutched flax	Retted-scutched flax
No. of experiments	50	38	27
Mean yield of all experiments	46·8	5·28	4·37
Gain in yield from a dressing (per acre) of:			
1 cwt. ammonium sulphate	2·6	0·09	0·29
3·5 cwt. superphosphate	0·8	0·09	0·05
1·8 cwt. muriate of potash	0·7	0·22	0·08

Total crop yields were increased slightly by nitrogen, but the returns from phosphate and potash were very small. The experiments in 1940, 1941, 1942, 1943 and most of those carried out in 1944 were processed by a dry-scutching method which avoided retting; very

small average increases in yield of green-scutched flax were given by nitrogen and phosphate, but potash gave a somewhat larger increase. Such small crop responses make it difficult to justify any general recommendation to use fertilizers on flax. At present prices the extra yields of green-scutched flax were approximately sufficient to pay the cost of the nitrogen and potash fertilizers used, but the average return from superphosphate was not sufficient to pay for the dressing. The way in which the experiments were processed appeared to affect the returns obtained from fertilizers. The

	Response to ammonium sulphate, cwt./acre	
	Total crop	Scutched flax
Per cent of N in soil:		
To 0·2	2·8	0·14
0·21–0·3	3·0	0·00
Over 0·3	1·0	—0·07
History of land:		
Old arable	3·3	0·18
Ploughed from grass	1·5	—0·02

produce of some 1943 experiments and of all those carried out in 1944 and 1945 was processed by retting followed by scutching. On the basis of all experiments providing yields of retted-scutched flax, manuring with phosphate and potash lost money, but nitrogen was profitable.

Analyses of soils taken from the sites of the experiments were examined to see if chemical methods could be used to pick out the more responsive fields. The response to nitrogen fertilizer was examined by separating the centres according to the percentage of nitrogen in the soil and also, where possible, from knowledge of the previous history of the land. Groups of experiments which were

Soil analyses, mg. of P_2O_5 (or K_2O) per 100 g. of soil	Response, cwt./acre	
	Total crop	Scutched flax
To superphosphate		
Citric acid soluble P_2O_5:		
"Low" (to 8)	3·0	0·49
"Medium" (9–16)	0·4	—0·03
"High" (over 16)	—0·1	—0·04
To muriate of potash		
Acetic acid-soluble K_2O:		
"Low" (to 10)	1·5	0·48
"Medium" (11–16)	0·6	0·21
"High" (over 16)	—0·1	—0·10

on old arable land or which were on soils containing less than 0·2 per cent N gave worthwhile responses to nitrogen fertilizer. Solubilities of soil phosphorus in 1 per cent citric acid and of soil potassium in 0·5*N*-acetic acid were used to provide the groupings of the above experiments.

By restricting dressings of superphosphate to those soils with "low" citric acid-soluble soil phosphorus manuring would have been quite profitable; experiments on groups of soils with "medium" and "high" soil phosphorus gave no return on average from phosphate

dressings. In the same way the average increase in yield of scutched flax from muriate of potash applied to the group of soils having " low " values for acetic acid-soluble potassium more than repaid the cost of the fertilizer, but dressings of potash given to soils which were " high " in soluble potassium would have resulted in a loss. The experiments showed that fertilizers were justified for flax only when there was evidence from chemical determinations, or from experience, that the soil was deficient in one or more of the major plant nutrients.

Oil-palm (W. B. Haines)

Examination of data from the West African oil-palm experiments (*Rep. Rothamst. exp. Sta. for* **1956**, p. 49) has now been completed. It has yielded much new information on the possibilities of improving oil-palm yields by means other than manuring which may be of economic importance. The yields of individual palms show a very distinct rhythmic cycle, and peak yields stand out clearly and generally occur every 3 years. The average peak yield for each palm is about 80 per cent greater than the mean yield for the palm. It is suggested that this cycle is due to the fruiting phase having a shorter natural period than the weather. When the fruiting phase and suitable weather coincide, then peak yields are likely to be produced. The peak years appear to be the normal performance of palms which have suffered no check to fruiting. Poor yields which are obtained in years between the peaks may be regarded as losses which might be prevented if the vulnerable phases during the fruiting cycle can be identified. In the experiments the cyclic rhythm was not influenced by manuring treatments, by the sites used or the variety of palm grown.

Soil Nitrogen

Fixed ammonium nitrogen in soils and clay minerals (J. M. Bremner)

The use of hydrofluoric acid for the extraction and determination of fixed ammonium-nitrogen in soil (*Rep. Rothamst. exp. Sta. for* **1956**, p. 53) has been studied in detail. Experiments with vermiculite and other clay minerals containing fixed ammonium showed that neither hydrofluoric acid nor hydrochloric acid released as much ammonia as did mixtures of the two acids. Fixed ammonium was completely extracted from vermiculite by treating the mineral with a mixture of 1*N*-HF and 1*N*-HCl for 24 hours at room temperature. This acid-extraction procedure was applied to soil samples from various profiles and indicated that 3–8 per cent of the nitrogen in the surface soils, and 10–50 per cent of the nitrogen in the subsoils was in the form of fixed ammonium. The possibility that soil nitrogen compounds are decomposed by the HF : HCl mixture with formation of ammonia could not be tested directly, but experiments with organic soils, and with various organic nitrogen compounds, indicated that estimates of fixed ammonium obtained by this procedure are not seriously affected by such decomposition. However, a comparison of different methods of determining ammonium-nitrogen in hydrofluoric acid extracts of soils showed that techniques previously adopted for this determination

gave erroneous results due to decomposition of organic nitrogen compounds. Methods based on distillation with magnesium oxide at 25° or with a borate buffer (of pH 8·8) at 100° appeared to be reliable when they were modified to eliminate interference due to hydrofluoric acid. Experiments with vermiculite showed that ammonium-nitrogen fixed by this mineral was determined quantitively by the Kjeldahl method.

While working at Iowa State College J. M. Bremner has shown that fixed ammonium-nitrogen can be extracted quantitatively from vermiculite by treatment with cation-exchange resins in the sodium or hydrogen forms. The use of this method for extracting fixed ammonium-nitrogen from other clay minerals and from soils is now being explored.

The results of these investigations on the occurrence of fixed ammonia in soils may help to explain the facts that a large proportion of soil nitrogen is liberated as ammonia by acid hydrolysis, and that the carbon : nitrogen ratios of many soils decrease markedly with depth in the profile.

Extraction of soil nitrogen compounds (J. M. Bremner)

Hydrated silicate minerals are believed to interfere with the extraction of soil organic matter. Further investigations on the effect of treating soils with hydrofluoric acid to destroy interfering minerals have shown that pretreatment with *N*-HF : *N*-HCl at room temperature has no significant effect on the quantity of soil nitrogen extracted subsequently by 0·5*M*-sodium hydroxide or neutral 0·1*M*-sodium pyrophosphate. This pretreatment dissolved a considerable amount of soil nitrogen, and over 90 per cent of the nitrogen in Rothamsted soils could be extracted with repeated treatments with *N*-HF : *N*-HCl and 0·5*M*-NaOH at room temperature. The acid reagent dissolved considerably more soil nitrogen than did neutral sodium pyrophosphate, and it proved to be more effective than 0·5*M*-NaOH in extracting nitrogen from some subsoils. A single pretreatment with *N*-HF : *N*-HCl dissolved 15–29 per cent of the nitrogen from surface soils and 30–68 per cent of the subsoil nitrogen. Hydrofluoric acid releases nitrogen compounds associated with clay minerals which are not extracted by the neutral and alkaline reagents generally used to extract soil organic matter.

Distribution of forms of nitrogen in soil profiles (J. M. Bremner)

The distribution of the forms of nitrogen in three soil profiles has been studied by determining the amounts of total-, α-amino- and ammonium-nitrogen released by acid hydrolysis. It was found that the proportion of soil nitrogen released by hydrolysis as acid-soluble- and amino-acid-nitrogen decreased with depth, whereas the proportion liberated as ammonia increased with depth. The proportion of soil nitrogen dissolved by 0·5*M*-sodium hydroxide or by neutral 0·1*M*-sodium pyrophosphate decreased with depth, whereas the proportion dissolved by *N*-HF : *N*-HCl increased with depth. The carbon : nitrogen ratios of both alkali and pyrophosphate extracts increased with depth in the profile.

Transformation and movement of fertilizer nitrogen (J. K. R. Gasser)

Concentrations of nitrate and ammonium in the surface soil of the plots of an experiment on sandy loam at Woburn were measured at intervals during the period April to October. Ammonium sulphate, calcium nitrate or urea were added to plots on which rye-grass was sown at the beginning of April, and also to plots which were uncropped. Under grass there was no loss of inorganic nitrogen from the soil for 5 weeks after sowing, thereafter uptake was rapid, and when the grass was cut in late July all the nitrogen applied as fertilizer had been removed. At subsequent samplings inorganic nitrogen levels under grass were the same on plots which had received nitrogen fertilizer in spring as on unfertilized plots. On uncropped land which received no nitrogen fertilizer NO_3–N reached a maximum value of 15 p.p.m. in July, but with wet weather in July and August nitrate levels fell and were only 2 p.p.m. in October. Nitrification of added ammonium sulphate on uncropped land appeared to be hindered by dry weather, and was not completed until 20 weeks after the fertilizer was applied. All the urea applied to uncropped land had been transformed to ammonium 8 weeks after application, and the final transformation to nitrate was completed within 20 weeks. April was a very dry month, rainfall in May was below average, but it was slightly above average in June and July. There was no loss of nitrogen applied as fertilizer from the surface 6 inches of soil until late July. From the end of July onwards, nitrate in the top-soil decreased, and at the final sampling in October more than four-fifths of the nitrate applied to uncropped land in April had been lost from the top 6 inches. Deeper soil samples taken in October showed that nitrate had moved to a depth of 3 feet below the surface, the maximum nitrate concentration at that time being 1–2 feet deep. This work on the light soil at Woburn confirms that carried out on heavy land at Rothamsted in 1956 (*Rep. Rothamst. exp. Sta. for* **1956**, p. 53). On uncropped land at both stations urea and ammonium sulphate were converted to nitrate much more slowly than had been anticipated; nitrate was not leached out of the surface layer of either soil by moderate summer rainfall, and leaching was only effective in prolonged wet periods. In each year where grass was grown both ammonium and nitrate were removed rapidly and practically all the fertilizer nitrogen had been taken up at the first cutting of grass.

Leaching of nitrate from soils (R. Webster and J. K. R. Gasser)

Laboratory experiments were carried out to study the way in which nitrate may be leached from columns of soils. A clay-loam soil from Rothamsted and a sandy loam from Woburn behaved similarly. Nitrate was leached more rapidly from fine (<2 mm.) soil than from coarser (2–10 mm.) fractions; the rate of loss was still smaller from unsieved soil. In other experiments the progress of nitrate down the columns during leaching was followed. These suggested that initially leaching water removed nitrate from the surface of structural units; later, when the soil mass was saturated with water, nitrate contained *inside* soil aggregates was lost.

Mineral- and mineralizable-nitrogen under winter wheat (J. K. R. Gasser)

Existing levels of mineral nitrogen and also "mineralizable"-nitrogen determined by an incubation procedure were measured on soil samples taken from the unmanured plots of four winter wheat experiments. NH_4–N and NO_3–N were determined on the fresh samples and also after incubation at 20° for 30 days. The total mineral-N content was high and fairly constant during dry weather in November and early December, averaging 22 p.p.m. When heavy rain fell during December the mean values fell to 6 p.p.m. NH_4–N and 2 p.p.m. NO_3–N. The mean level of NH_4–N then remained at about 5 p.p.m. until the following August. The mean NO_3–N content was 2 p.p.m. until April, it fell to 1 p.p.m. during May and June, and at harvest in late August was again 2 p.p.m. The mean increase in total mineral nitrogen on incubation showed a marked rise in January following wet weather at the end of December. This higher level of mineralizable-nitrogen was maintained until late March, after which date a gradual decline occurred. By harvest the amount of NH_4–N plus NO_3–N produced on incubation was again at the level measured the previous autumn when the work began.

Soil Phosphorus

Phosphate concentrations in soil in relation to crop growth (G. E. G. Mattingly)

A group of soils from Rothamsted and from Forestry Commission Nurseries, which had different mechanical compositions and different manurial histories, were used in a greenhouse experiment to study the relationship between yields of ryegrass and soil phosphate concentrations (measured after equilibrating soils with 0·01*M*-calcium chloride). The grass grew more rapidly on the light forestry soils,

Table 7

Soil phosphorus concentrations before and after cropping, yields of dry matter and "A" values of soils used in pot experiments on ryegrass

		P concentration × 10^{-6} M		Yield, g./per pot		"A", mg./P 100 g. soil
		Before cropping	After cropping	1st cut	Total in 4 cuts	
Forest nursery soils:						
Wareham	without phosphate ...	5·2	0·03	1·24	2·14	1·2
	with superphosphate	13·1	0·07	3·56	7·58	3·4
Ringwood	without phosphate ...	2·0	0·03	2·93	9·54	5·4
	with superphosphate	6·9	0·06	4·21	15·54	9·6
Rothamsted soils:						
Hoosfield	without phosphate ...	0·3	0·03	0·89	3·59	3·4
	with superphosphate	4·0	0·12	4·13	17·02	30·8
Broadbalk	without phosphate...	0·3	0·03	1·71	6·87	5·7
	with superphosphate	3·2	0·17	4·18	16·58	30·0

which had high phosphate concentrations initially, than on the heavier calcareous soils from Rothamsted. Nevertheless, the Rothamsted soils produced higher yields of total dry matter in four

cuts of grass in spite of their much lower initial phosphate concentrations. Typical yield data are given in Table 7 together with "A" values and the phosphate concentrations measured before and after cropping. The experiment was continued for 4 months and at the end soil phosphate concentrations had been greatly reduced; in some of the lighter soils from forestry experiments concentrations were less than 1 per cent of the initial values, and they were very difficult to measure. Phosphate concentrations after cropping were invariably higher on soils that had previously received dressings of superphosphate in the field. The *initial* rate of growth of ryegrass in this experiment depended largely on the phosphate concentration in the soil, but the *total* yield obtained was approximately proportional to the total labile phosphate.

Isotopic exchange of phosphate in soils in relation to uptake by ryegrass (G. E. G. Mattingly and O. Talibudeen)

The amounts of phosphate that undergo isotopic exchange in 24 hours (designated "rapidly labile" or P_{24}) and in 150 hours (designated "total labile" or P_{150}) were determined in 19 soils before and after cropping with ryegrass in greenhouse experiments. Differences between total labile phosphate are given in Table 8, together with the mean quantities of phosphate removed by the ryegrass. On average of the whole group of soils the amount of phosphate taken up by ryegrass corresponded closely with the decrease in total labile phosphate which occurred during cropping. The labile fraction of soil phosphate for the group of acid soils from forest nurseries was overestimated when compared with the phosphate taken up by ryegrass, perhaps because 0·001*M*-citrate was used to determine the values. The grass removed approximately half of the original total labile phosphate on average of this group of acid soils and of the group of calcareous soils from Rothamsted.

TABLE 8

Comparison of the phosphate removed by ryegrass with the changes in the total labile phosphate (P_{150}) caused by cropping (all measurements are of mg.P/100 g. of soil)

	No. of soils	Mean total labile P Before cropping	Decrease after cropping	Mean total P removed by ryegrass
Forestry soils (acid)	10	9·72	6·97	4·69
Rothamsted soils (calcareous)...	9	12·46	6 27	7·38
All soils	19	11·02	6·64	6·02

In all soils except three the ratio of rapidly labile to total labile phosphate (P_{24}/P_{150}) was lower after cropping than in the original soils. This suggests that ryegrass uses rapidly labile phosphate preferentially. In three Rothamsted soils that have never received phosphate fertilizers, phosphate appeared to be taken up by ryegrass from the rapidly labile and total labile fractions in the same proportions, there being no decrease in the ratio P_{24}/P_{150} after cropping.

The total yields obtained from four cuts of grass taken over 4 months were related exponentially to values for the total labile phosphate (P_{150}) of the soils used.

Phosphate residues in Rothamsted soils (G. E. G. Mattingly)

Earlier work (*Rep. Rothamst exp. Sta. for* **1954**, p. 44) showed that about one-third of the residual phosphate remaining in the slightly calcareous soils of the Hoosfield Exhaustion Land (which had received heavy dressings of superphosphate before 1901) undergoes isotopic exchange in laboratory and greenhouse experiments. This study was continued by measuring labile phosphate ("A" values) using ryegrass grown (in pots) on soils from Hoosfield Permanent Barley, Broadbalk Permanent Wheat and Barnfield Permanent

TABLE 9

"A" values of Rothamsted soils determined in pot experiments on ryegrass

	Total P, mg./100 g. soil	"A", mg./100 g. soil	Increase in "A" as percentage of increase in total P
Broadbalk:			
No phosphate	60·5	5·7	
Superphosphate since 1843 ...	115·2	30·0	44
Hoosfield:			
No phosphate	52·0	3·4	
Superphosphate since 1852 ...	129·3	30·8	35
Barnfield:			
No phosphate	89·1	15·6	
Superphosphate since 1876 ...	125·0	27·0	32

Mangolds Experiments (Table 9). These soils, in contrast to those of the Exhaustion Land studied previously, receive annual applications of superphosphate and a slightly higher percentage of the residual phosphate in them is readily labile. Using these data, and the total amounts of superphosphate applied to the Exhaustion Land, it appears that in 1901, when manuring of this site stopped, the labile and total residual phosphate contents of these soils were about 20 mg. P and 60 mg. P/100 g. of soil respectively. R. G. Warren has shown, however, that since 1901 the total phosphate removed by crops from the Exhaustion Land soils containing superphosphate residues is about 40 mg. P/100 g. soil. It seems, therefore, that over a *long* period of continuous cropping more phosphate is taken out of the soil than was originally present in an isotopically exchangeable form.

Isotopic exchange of phosphate in Rothamsted soils (O. Talibudeen)

The influence of the other ions present in solution on values for isotopically exchangeable (i.e. labile) soil phosphate has been studied further by comparing the effects of 0·001*M* solutions of citric acid

and diethyl-barbituric acid. Temperature has been found to have some effect on values for labile phosphate, and measurements suggest that a change in the nature of isotopically exchangeable phosphate may occur between 35° and 45°. Graphical analysis has been used to subdivide total labile phosphate into " rapid ", " medium " and " slow " fractions (with P. Arambarri).

Very small concentrations of organic anions markedly increase the specific rate of exchange of phosphate ions in the " rapid " and " medium " fractions; increasing the temperature above 35°, in the absence of organic anions, causes a marked increase in the specific rate of exchange of the " medium " and " slow " fractions.

Decomposition of Plant Residues in Grassland Soils

(K. Shaw)

Work on the decomposition of the mats which are formed on large areas of permanent pasture on marginal land has been completed. These mats retain many of the characteristics of plant material; they are unlike the organic matter of normal mineral soil, as they contain much cellulose and hemicellulose and their lignin has a high methoxyl content. Cellulose and hemicellulose contents decrease down the mat profile and the lignin-like material increases, but the methoxyl content of the lignin fraction remains unaltered. When the mats were decomposed in the laboratory, the hemicellulose fraction remained constant but cellulose rapidly disappeared and the lignin fraction increased. The organic compositions of the mature grasses from which the mats were formed were very similar to those of good agricultural grasses which rarely seem to form mats. The mats used in this work had formed over very acid soils and were themselves very acid and very deficient in bases. When the pH was raised to neutrality by adding lime the mats decomposed rapidly in laboratory incubation experiments. Adding phosphate and inorganic nitrogen salts to the incubating mats decreased the rate at which CO_2 was produced, but these treatments increased the rate of decomposition slightly when lime was added as well. Phosphate increased the rate of mineralization of the organic nitrogen in the mats both in the presence and in the absence of lime. Decomposition was very slow at 2°, but increased with increasing incubation temperatures. The amount of moisture present did not have a large effect on rate of decomposition, although each mat examined appeared to have an optimum moisture content at which it decomposed most rapidly. The organic nitrogen present was converted to ammonia quite readily, even under water-logged conditions. Mixing the underlying mineral soils with the mats decreased their rates of decomposition slightly.

The persistency of these mats in the field appears to be due mainly to their high acidity and low base status. In improving such land adequate liming will be essential to promote decomposition of surface mat. In addition, the mats must be treated mechanically to disintegrate them and to mix the organic layers thoroughly.

The Effects of Cropping and Manuring on Soil Fertility

Arable rotation at Saxmundham (G. W. Cooke, G. E. G. Mattingly and R. J. B. Williams)

The Rotation I Experiment at Saxmundham was carried on for many years by the East Suffolk County Council; recently it has been in the charge of the National Agricultural Advisory Service. Wheat, mangolds, barley and a legume have been grown in a four-course rotation with constant annual manuring which has compared all combinations of sodium nitrate, superphosphate and potassium chloride; bone meal and farmyard manure have been tested as well. There have been large responses by all crops to phosphate fertilizers; nitrogen has increased yields of all non-legumes, but responses to potash have been smaller. The soils were sampled and analysed after 56 years of continuous cropping and manuring. Farmyard manure applied at 6 tons/acre each year has increased the total nitrogen and carbon in the soils by about 50 per cent (as compared with plots receiving fertilizers); plots which have had nitrogen and phosphate fertilizers now contain slightly more organic matter than plots which have not had these fertilizers. The total amount of soil phosphorus has been built up by farmyard manure and by bone-meal dressings and, to a lesser extent, by annual dressings of 2 cwt./acre of superphosphate. "Soluble phosphate" estimated by several methods differentiated clearly between plots dressed with phosphate and those which had received none. 0·3*N*-HCl gave very high values on plots treated with bone meal. This extractant is satisfactory for most Rothamsted soils, but it is known to be unreliable when used on soils containing residues of bone meal or rock phosphate. The amounts of phosphate dissolved by 0·5*M*-$NaHCO_3$, and those which were in equilibrium with 0·01*M*-$CaCl_2$, placed the soils of all the plots in the same order, which agreed qualitatively with differences in the estimated amounts of phosphorus removed by the crops during the 56-year period. The total potassium content of the soils is too high for the effects of either potash manuring or removal of potassium by crops to be detected. The values for exchangeable potassium in the soils of the plots were closely related to the losses or gains of soil potassium calculated from the known manuring and the estimated uptake by crops. It is possible that potassium deficiency would develop on the plots of this experiment which do not receive potash fertilizers if heavier crops were grown by using higher rates of nitrogen.

The effect of nitrogen manuring of grassland on soluble potassium in soil (R. J. B. Williams)

An experiment at Rothamsted comparing various forms of nitrogen fertilizers for Italian ryegrass provided an instance of the severe drain imposed on soil potassium supplies when grassland is manured heavily with nitrogen fertilizer. A basal dressing of potash fertilizer (0·83 cwt. K/acre) was applied over the whole area and the grass was cut four times during the season. Soil samples taken from individual plots at the end of the season had the following amounts of potassium soluble in 0·3*N*-HCl:

	Mg. K/100 g. soil	Total K removed by crop, cwt./acre
Without nitrogen	9·8	0·46
With ammonium sulphate supplying:		
0·2 cwt. N before each cut	7·4	0·97
0·4 cwt. N before each cut	4·9	1·46

Heavy nitrogen fertilization had reduced soluble potassium to half of the amount present on plots which had received no nitrogen, and at the end of the season grass on plots receiving nitrogen was showing potassium-deficiency symptoms.

Analytical

Fluorine (A. C. D. Newman)

Investigations on the development of a reliable method of determining fluorine have been completed. The effect of fluoride on the colour reaction between quinalizarin and aluminium salts was further investigated. A water-soluble sulphonate of quinalizarin (1 : 2 : 5 : 8-tetrahydroxyanthraquinone) was prepared and its U.-V. and visible molecular extinction curve recorded. The reaction of this derivative with aluminium was investigated spectrophotometrically, and it was found that a complex was formed which exhibited two absorption peaks, one at 265 mμ and one at 495 mμ. The latter absorption peak was used to examine the influence of fluoride ions on the complex; at pH 3·9 the absorption was markedly decreased by fluoride. A procedure was developed to use this bleaching to determine small quantities of fluoride, and it was applied to the estimation of fluorine in rock phosphates. This application showed, however, that the absorption of the reagent was dependent on pH to an extent which made the method accurate only when very close control of pH ($\pm$0·01) was possible. However, its simplicity enabled the method to be applied to the semi-quantitative analysis of large numbers of solutions per day.

The classical method of determining fluorine by titration with thorium nitrate suffers from interference by aluminium, ferric ion, calcium, phosphate and sulphate, all of which may be present when rock phosphates are dissolved. It was found that fluoride may be separated from phosphate and the anionic metal chelates of ethylenediaminetetra-acetic acid by absorption on, and elution from, an anion-exchange column containing a strongly basic resin. Development of this principle was shown to provide a simple and accurate method of removing interfering ions. It is a satisfactory alternative to the distillation of fluorine (as fluorosilicic acid) which is generally employed. The procedure developed was used to determine fluorine in rock phosphates and gave values similar to those obtained by standard methods.

Iron (S. N. Chakravarti and O. Talibudeen)

The bright-red complex produced by the reaction between *o*-phenanthrolene and ferrous sulphate has been used to estimate iron. The method has been adapted to work at very low concentrations (0·04–6 p.p.m. Fe) and was used to determine ferric and ferrous iron in the aqueous phase of acid soils. The colours produced were stable, and there was no interference from acetate buffer solutions of various pH values or from phosphate up to 50 p.p.m.

PEDOLOGY DEPARTMENT

A. Muir

D. M. C. MacEwan returned from his secondment to the University of Granada, and has since resigned to take up a post in University College, Dundee. I. Stephen returned from the University of Illinois, where he spent nine months in the Agronomy Department teaching and supervising post-graduate research work. Messrs. R. R. Storrier and J. Loveday have been carrying out laboratory studies on soils they have been mapping in conjunction with the Soil Survey. Mr. D. H. Khan of Dacca University completed his research work on soils derived from calcareous rocks for which he was awarded the degree of Ph.D. of London University. R. Greene-Kelly was selected to study in Moscow under the Royal Society Exchange Scheme.

Mineralogy

Picrite weathering (*Shropshire*)

The work has been confined to a more detailed study of two of the weathering products mentioned in last year's report—fibrous montmorillonite and iddingsite. The specimen of the latter used for this study is from an Australian source.

(a) *Fibrous montmorillonite mineral*

X-ray fibre patterns of air dry material have been measured and a cell $a = 5{\cdot}3$ Å. (fibre axis), $b = 9{\cdot}2$ Å., $c = 15{\cdot}0$ Å., $\beta = 96$–$98°$ fits the observed reflexions. The indexing is based on zero, first and second layers. Reflexions of the type $00l$, $0kl$ and hkl have been unambiguously indexed in terms of the above cell. The occurrence of hkl reflexions shows without any assumptions that the material is ordered in three dimensions. More reflexions and more precise measurements will be needed to index the pattern more fully; the difficulties are that the cell is large and also the reflexions, being somewhat broad, cannot be measured precisely.

A cation-exchange capacity of 96 m.e./100 g. air-dry material has been obtained by saturating with calcium nitrate and replacing with magnesium nitrate solutions. (G. Brown.)

(b) *Iddingsite*

X-ray work on the iddingsite mentioned in last year's report has continued in order to establish the nature of the material and to find its relation to the original olivine. Because the crystals give weak diffuse spots and streaks, it was necessary to use oscillation photographs to establish the nature of the reciprocal lattice. Complete sets of oscillation photographs have been obtained about three axes, and a preliminary analysis of these shows that the crystals consist of three phases, unaltered olivine, a goethite-like material

and a material which is probably a 2 : 1 layer lattice silicate. The olivine was identified by comparison with a rotation photograph of known olivine in the same orientation. The goethite-like material is in parallel alinement to the olivine with the 10 Å., 6Å. and 4·7 Å. olivine axes parallel to the 10 Å., 3 Å. and 4·6 Å. axes of the goethite-like material. The layer lattice mineral is also in parallel alinement with the 10 Å., 6 Å. and 4·7 Å. olivine axes parallel to 5 Å., 9 Å. and 15 Å. axes of the layer lattice material.

The olivine phase gives sharp spots and appears to be a single crystal or a few small fragments of a single crystal, probably a relic of the original olivine. The goethite-like phase gives diffuse spots which show that this phase is in the form of a large number of very small crystals in parallel alinement. The layer lattice mineral shows broad 00*l* spots and a hexagonal array of *hk* streaks which show that it is composed of small crystals in parallel alinement and also that there is lack of order in the stacking of the layers. In addition to these phases there are a number of spots which appear to be superlattice reflexions from the goethite-like phase, possibly due to disorder of the cations.

It appears that in the alteration of the olivine the original lattice of close-packed oxygens has not been greatly disturbed and that the changes have occurred by the movement of cations within small regions to form microcrystals of the alteration products. The parallel alinement of the major components of our iddingsite explains why it behaves optically as a single crystal. The same explanation probably holds for all iddingsites which show coherent optical properties. In certain aspects this work does not agree with the results of the recent study of iddingsite by Ming Shan-Sun (*Amer. Min.* 1957, **42**, 525–533), who states on the basis of examination of iddingsites from New Mexico that goethite is the only crystalline phase and that the other substances shown by chemical analysis are largely amorphous. (G. Brown.)

Glauconite in Lower Greensand

Optical examination of some samples of this formation and also of associated soils in Bedfordshire and Buckinghamshire has shown that glauconite (and its alteration products) occurs only in small amounts in the fine sands examined. Dilute acid extraction, which probably decomposes only the glauconite present, showed an average of about 20 p.p.m. K, with a maximum value of about 40 p.p.m., confirming the paucity of the mineral in the sands of the materials examined. (I. Stephen and C. L. Bascomb.)

Jarosite

A pale-yellow fine-grained powder which occurs in cracks and veins in soil from Bow Brickhill has been identified by X-ray powder diffraction as jarosite, a basic potassium iron sulphate. Optical and chemical tests confirm this identification. Previously unidentified lines on X-ray patterns of clays of some soils from Romney Marsh were subsequently identified as jarosite lines, and examination of the soils showed small amounts of pale-yellow powdery material. Both the iron and sulphur are probably derived from pyrite, and the alkali from other minerals, possibly clays, by acid attack. Dilution

and leaching of such solutions could precipitate jarosite which, once precipitated, is not readily redissolved in water. This appears to be the first time that jarosite has been identified in soils, although its occurrence is not surprising. (G. Brown.)

Clay Mineralogy

Soil clays

Soil samples examined by X-ray methods in the past year included several from abroad—from Iraq, Borneo, Kenya and Somaliland.

The Iraq soils and some of Somaliland profiles contained appreciable quantities of palygorskite, the X-ray results in some cases being checked by electron-micrography. The Iraq soils confirm the impression that this mineral is widespread in the Middle East, having been found in the Syrian desert (Muir, *J. Soil Sci.* 1951, **2**, 169) and in soils of the Karun delta and the foothill region of South-West Persia. The relationship to rock formation (i.e., Tertiary) pointed out earlier would seem to be in part confirmed by the Somaliland soils, which are associated to a considerable extent with Eocene rocks.

Of a number of forest soils from Borneo, some were interesting in showing a moderate to high content of gibbsite in their clay fraction, particularly a peaty mountain soil on granite, the subsoil clay of which consisted largely of that mineral. The Kenya soils were the upper horizons of a profile which included parent rock of trachytic affinity and weathered material above this. The main clay minerals proved to be kaolin and mica, with some haematite. Several thin sections of the rock and its weathered counterparts have been made.

In addition to these—samples of clay balls of unknown origin containing plant remains were received from the Rhodes–Livingstone Museum, Rhodesia, and were examined for clay mineral content and other things with a view to determining their origin.

British samples examined include a number from Buckinghamshire, Hertfordshire, Worcester, Kent and Shropshire, sent in by soil surveyors. A survey of the clay minerals of clays and limestones at all levels of the geological column in England and Wales has been undertaken. The Geological Survey and Museum has supplied a number of specimens, seventeen of which have already been examined for clay mineral content. It is also hoped to examine the heavy minerals of some of these materials. (A. M. Du Feu.)

X-ray structure analysis

The programmes for crystallographic calculations using the Elliot 401 computor written in collaboration with J. C. Gower (Statistics) were described at an Institute of Physics X-Ray Analysis Group meeting (*Brit. J. appl. Phys.* **9**, 1, 1958). Work on the structure of muscovite using these programmes has for the moment been set aside, since it has been found that very similar work is already being done by E. W. Radoslovich at the Waite Institute. The programmes have proved very useful in completing two pieces of work done elsewhere and now prepared for publication—" The crystal

structure of a hydrated nickel cyanide ammonia complex ", by J. H. Rayner and H. M. Powell, and " The crystal structure of sodium formaldehyde bisulphite ", by J. H. Rayner. (J. H. Rayner.)

Black Jack Mine Beidellite

Work has continued on this mineral to establish it as a true end member of the montmorillonite–beidellite series and to investigate its properties fully.

Optical work. A thin section of the naturally occurring material has been made and examined with the petrological microscope. Typical lath-shaped flakes occur in small spherulites with their long axes radially arranged and the expanding *c*-axis as the other most frequently seen. When the material is converted to the sodium form without dispersion the spherulites break down into smaller units having the appearance of small closed fans of material. If these fans are treated with successively more dilute sodium chloride solutions they swell in the manner of montmorillonites beyond the limits of crystalline swelling and the laths rotate as the " fan " opens. Examples of these expanded fans have been obtained with the electron microscope.

The values of the higher of the two refractive indices determined on K, Na and Ca oriented aggregates which had been heated to 280° C. to expel interlayer water were 1·557, 1·545 and 1·525 respectively and the birefringence 0·035 in each case. X-ray examination showed that appreciable lattice penetration of the 1-bromo-naphthalene and paraffin oil mixture had taken place, giving rise to 14 Å., 14·4 Å. and 16·5 Å. basal spacings. A controlled expansion was tried using a glycerol, water and potassium mercuric iodide mixture. However, the oils changed refractive index rapidly in air and, as the material reached equilibrium slowly in each oil, the method was difficult to use.

X-ray work. The small fans of material seen in the light microscope are too small to be used directly in the X-ray cameras, and oriented aggregates have to be used instead. If a small amount of water is added to the sodium beidellite and the resulting gel dried on to a glass surface a high degree of orientation is achieved without complete dispersion of the fans. The resulting X-ray pattern, the best results are given with the single-crystal camera, shows discrete *hkl* reflexions instead of the usual montmorillonite bands. Assuming an orthorhombic unit cell for the ethylene glycol saturated Na-flake, the geometry of these reflexions has been calculated and shown to fit the pictures obtained. If the aggregates are made from better-dispersed material the reflexions merge and become band-like. It is not yet clear whether powder patterns from the naturally occurring undispersed clay show a symmetry other than orthorhombic.

The new diffractometer was used with an oriented aggregate of Na-beidellite expanded with ethylene glycol. The relative intensities of twenty 00*l* reflexions with a basal spacing of 16·9 Å. were measured. Previously only fourteen orders had been obtained using 9-cm. powder cameras. Structure factors were calculated for an assumed structure and Fourier syntheses made on the computer using a programme by J. C. Gower. The refined structure had an " R factor " of about 16 per cent and showed that the distribution

of ethylene glycol, as seen in a one-dimensional projection, is more likely to be in a flat-topped peak for each layer of molecules than in two equal well-defined peaks for each layer, as suggested by Brindley in his work on allevardite. It is hoped to repeat this work using molybdenum radiation to give greater resolution.

Electron microscopy of clay minerals.

Work has continued with H. L. Nixon on the beidellite and other problems of clay mineral microscopy. The coming of the Siemens microscope has shown that with a machine capable of high resolution and contrast, the greatest clarity of detail even for the 10 Å. or 20 Å. flakes of montmorillonite is given with unshadowed mounts.

A new method of mounting has been used in which a minute amount of Na-beidellite was placed on a collodion grid and sprayed with water to cause partial dispersion. This has resulted in a characteristic and quantitative sample of the whole being obtained, and shows the existence of an amount of very small particle-size material together with the fans of large laths previously described. The nature of this small material is not yet known, but will be investigated.

A new technique has been worked out to measure particle thicknesses of 10 Å. or 20 Å. Montmorillonite flake edges of 60–200 Å. in height are photographed before and after shadowing. The step height, which is great enough to be measured accurately at a magnification of 35,000, is obtained from the shadowed picture, and the unshadowed one photometered to relate the density of the flake whose shadow has been measured to that of the smallest density change obtainable. Results on the few photographs of beidellite measured show that flakes 10 Å. thick are found and are quite visible but seem to be produced in quantity only with very careful dispersion.

Physical Chemistry of Soil Minerals

The mechanism of aggregate formation in soils

Last year's work has been continued. One case of the theoretical relation between water-vapour interfacial area and the suction has been verified. Further examples are under investigation.

The calorimetric technique has been applied to the study of the behaviour of adsorbed liquid films at very high relative pressure, with the result that apparent discontinuities in film formation have been detected. These are being studied in greater detail.

An investigation has been made of the micro-structure of montmorillonite and kaolin powders by measuring the low-temperature nitrogen-adsorption isotherms on samples of different water contents. With montmorillonite the surface area is very sensitive to small additions of water, indicating that the exposed surface consists predominantly of cracks of the order of 3–10 Å. in width. These would be expected if irregular silicate sheets of 10 Å. thickness were laid one over another. Monolayer interlamellar expansion leads to no sudden change in structure either permanent or temporary, indicating that the aggregates have considerable rigidity at low

contents. Kaolinite showed, as was expected, much less dependence of surface area on water content.

The effect on the surface areas of wetting and drying sodium saturated powders of clay minerals has been studied. Montmorillonite forms coherent aggregates of very low surface area with cracking predominantly parallel to the (001) planes, the bigger cracks being easily visible under a microscope. There is no evidence that such a dried aggregate has a unique surface area dependent only on " particle size "; the surface area increases rapidly on disturbance, due probably to further extension of cracks and exposure of slits formed by imperfect packing of the silicate sheets. By contrast, dried illitic and kaolinitic aggregates have surface areas independent of previous treatment suggesting that the crystallites are comparatively loosely packed together. Further study on soil-derived materials of different particle sizes is planned.

Heats of wetting of clay minerals

A detailed study is being completed of the heats of wetting of clay and related minerals. The importance of the kind of exchange cation has been emphasized in earlier work, and in last year's Report the work of swelling was mentioned as another important factor. Further study has revealed that the charge density is also of importance. Of particular interest is the observation that when the relation for non-expanding minerals between the heat of wetting per unit area and the charge density is extrapolated to zero charge density, the heat per unit area is found to be equal to that of samples of quartz examined in the department. This suggests that these quartz samples are of low charge density whilst quartz samples mentioned in the literature as giving higher heats may well have higher charge densities.

Water adsorption by clay minerals

Studies on the water adsorption by members of the montmorillonite group have been continued. Preliminary correlation of the stability of the water layers with charge density has been made and has further emphasized the importance of this quantity in determining clay properties. Dehydration isobars of montmorillonite have been measured and compared with isotherms and d.t.a. curves, and this has now enabled a detailed interpretation of the latter to be made. Calorimetric studies are also in progress both of heats of adsorption of water and heats of solution of clay minerals (see last year's Report). (R. Greene-Kelly and R. G. Gallavan.)

Laboratory synthesis of clay minerals

The apparatus for the high-pressure synthesis of clay minerals has now all been received and is being set up in a high-pressure cubicle, giving the operator protection in the case of the sudden escape of steam. It should now be possible to extend the work on clay mineral synthesis begun last year using apparatus at the Imperial Chemical Industries Plastics Division at Welwyn Garden City. (J. H. Rayner.)

Apparatus

X-ray diffractometer

During the year a counter diffractometer has been installed. The new equipment comprises a Newton Victor Raymax 60 demountable X-ray generator, a Hilger Y.115 X-ray diffractometer and associated counting equipment supplied by Labgear. A demountable X-ray set was chosen to give maximum flexibility in choice of target materials.

Having chosen a demountable tube, it was necessary to use a monitoring system rather than attempt to stabilize the X-ray output, as slight changes in operating conditions can give rise to variations in output. We therefore use two counting channels, one to measure the diffracted X-ray intensity, while the other continuously measures the primary X-ray beam. The relative intensities at different settings are then given by the ratios of counts in test and monitor channels. The counting equipment is two Geiger tubes followed by two quench probes, feeding either the Labgear triple-gate ratio counter or two ratemeters which are followed by a chart recorder adapted for ratio recording. The chart recorder is used for routine work, but where more detail is required the line profiles are plotted point by point using the ratio counter.

The diffractometer originally operated with a two-slit system to define the effective source and the divergence of the beam. Using a vertical $6 \times 0{\cdot}6$-mm. focus in the X-ray tube in place of the first slit, we have been able to obtain high resolution with high intensities without using Soller slits. For example, in chart recording we are able to resolve the $\alpha_1\alpha_2$ doublet at $2\theta = 35 - 40°$ at a scan speed of $\frac{1}{4}°$ 2θ per minute. This performance is similar to that given by commercial units with Soller slit systems. We have also made and fitted a separate angle marker pen on the margin of the chart to the chart recorder which correlates chart translation counter-arm rotation. In this way the whole chart width is available for recording. (G. Brown and R. Farrow.)

Preliminary work on the adjustment and testing of the diffractometer indicated the necessity for a pulse generator, and a suitable instrument has been developed. It is capable of giving rectangular pulses of positive and negative polarity, and of variable amplitude and duration, at six switched pulse rates, ranging from 5–5,000 p.p.s. With this instrument it is now a simple procedure rapidly to check the operation of the count-rate indicating and scaling circuits of the diffractometer. (R. Farrow.)

Micro-focus X-ray tube, etc.

The micro-focus X-ray tube described in the Annual Report for 1956 has been in operation for most of the year, having been used in conjunction with a single crystal camera, an ordinary 9-cm. powder camera and two new cameras made during the year. These new cameras are a low-angle camera and a focusing camera of the Bragg–Brentano type. The low-angle camera has been designed to be adjustable in all directions with the minimum of trouble; variations in slit width, and distances between slits and specimen can be set up with ease. When used with the micro-focus set only two slit systems are necessary, though for special applications a third slit

can be used. All slits can be adjusted for width and independently for position. It has been found that the process of positioning the whole camera in relationship to the X-ray beam is not as difficult as was expected, providing the right sequence is followed; the same thing is true of the adjustment of the various parts of the camera itself. Spacings in the order of 500–600 Å. can be obtained with a specimen-to-film distance of up to 25 cm.

The focusing camera is of a conventional design, using a flat specimen and giving for any one setting only one side of the X-ray pattern. Variations in length of exposure and slit width enable varying degrees of resolution to be obtained, though there are limitations in the range over which the best resolution can be got; this is a normal feature of this type of camera and one of its main disadvantages, a disadvantage which is, however, offset by the short exposure time required. This is in the region of 15 minutes.

In the early part of the year some exploratory work was done on X-ray micro-radiography using the micro-focus tube. The best results were obtained with a fine-resolution emulsion and the contact method with the specimen in close contact with the film. Further work on this subject was not possible, as the fine-focus set was required for diffraction purposes with a larger-size focus than is suitable for micro-radiography.

Some preliminary attempt was made to obtain silicon radiation using one of the gas-sets. This was not successful owing to the considerable amount of ionization which took place inside the camera which had to be made a part of the X-ray set, in order that the losses of the very long wavelength radiation in window material should not occur.

It is hoped that further work on X-ray micro-radiography and on the use of silicon radiation will be possible by using an old electron microscope. With some modification this instrument will be used as an X-ray set for experimental purposes. (G. C. Dibley.)

High-frequency titrimeter

At the request of C. Bloomfield, a high-frequency titrimeter has been built. This instrument is based on the design of Stelzner and Kelly, and operates on a frequency of 250 Mc/s. It is a single-valve oscillator using a type 955 " acorn " triode with a resonant line-tank circuit. The titration cell, of 50 ml. capacity, is placed between the lines and the oscillator response to the changing electrical characteristics of the solution being titrated is followed by observing changes in grid current, after the manner of a grid-dip oscillator.

It is hoped that by means of this method titrations can be performed in the presence of strong concentrations of electrolyte, the instrument oscillating quite readily when the cell is loaded with 50 ml. of 1·2*N*-NaCl. A full investigation of the capabilities of this titrimeter is being carried out. (R. Farrow.)

Spectrochemistry

Geochemistry of Lias shales

Previous work on numerous specimens of Lower Lias shale from several sites has shown that a relationship exists between the

amounts of the trace elements molybdenum, vanadium, copper and nickel and of organic carbon. It has also been found that both the trace element and organic-carbon contents are related to that of calcium carbonate, rising to a maximum with 20–40 per cent $CaCO_3$. The evidence suggests that the latter relationship is primarily one between calcium carbonate and the organic matter with which the trace elements are associated. This in turn would seem to imply that the organic matter in the depositing material influenced the deposition of calcium carbonate.

The high levels of molybdenum in Lower Lias shales which are responsible for the teart disease on soils derived from them in central Somerset, have been shown also to occur in this same formation as far away as the Stowell Park borehole at Northleach (Glos.) and in the outcrop at Lyme Regis.

The fact that no confirmed cases of teart have been reported in the latter area can probably be ascribed to two causes; namely that the steep slopes here promote good drainage, so facilitating the removal of excessive molybdenum and at the same time result in no large areas of soil being derived from any one shale band particularly rich in it.

The zones of the Lower Lias, which in these localities are rich in molybdenum, also occur in the Vale of Glamorgan and give rise to soils over a wide area. Shales examined from this area, however, were found not to contain abnormal amounts, except at Lavernock Point near Cardiff. The absence of teart in Glamorgan therefore apparently results from the absence of excessive amounts of molybdenum in the formation here. This is probably due to the proximity of the contemporary coastline having caused conditions unfavourable to the deposition of the type of organic material which accumulated molybdenum.

Trace element survey of Broadbalk

The preliminary work on the trace-element content of Broadbalk (plots 2, 3, 5, 8, 10, 13, 17) reported by A. H. Weir and J. Beckett (*Rep. Rothamst. exp. Sta. for* **1955**) has been extended by the quantitative spectrographic determination of a number of elements in these plots. The results show a remarkable uniformity in the total amounts of these elements over the field, as is indicated by the following figures giving the maximum and minimum amounts found (in p.p.m.):

Co ...	...	17·3 ± 1·3 (plot 2) 17·3 ± 0·5 (plot 3)	to	21·5 ± 2·6 (plot 8) 21·5 ± 1·7 (plot 17)
Ni ...	...	23·0 ± 1·8 (plot 3)	to	31·2 ± 1·5 (plot 17)
Cu ...	...	20·5 ± 1·7 (plot 5)	to	27·8 ± 3·3 (plot 2)
Mn ...	...	623 ± 71 (plot 18)	to	686 ± 62 (plot 13)
Cr ...	...	45·8 ± 2·4 (plot 3)	to	63·5 ± 12·3 (plot 17)
Ga ...	...	17·0 ± 2·3 (plot 5)	to	22·3 ± 4·2 (plot 17)
V ...	...	55·0 ± 3·5 (plot 3)	to	73·3 ± 7·6 (plot 17)

While these figures indicate the general levels, interpretation of the differences would be dangerous in the absence of analytical data to show how much has been added with the fertilizers during the field's

history, but in this connection it may be significant that plot 3 (no manure since 1839) is lowest in several elements. (H. H. Le Riche and S. Burnett.)

Soil Chemistry

Activity of leaf extracts

Fractionation of aqueous leaf extracts by dialysis shows that, while the greater part of the activity in mobilizing iron resides in the dialysable fraction, the residual activity of the heavier molecular weight fraction is appreciable, and the sum of the amounts of iron dissolved at equivalent concentrations by the two fractions is, for several species, greater than the amount dissolved by the original extract. This effect cannot be due to the presence of artefacts, since a reconstituted extract prepared from the two fractions has quantitatively the same activity as the untreated extract.

Paper chromatographic examination shows that dialysis removes those polyphenolic constituents that are of sufficiently small molecular weight to permit their separation into discrete spots on the chromatogram; the polyphenols remaining in the dialysed extract are too complex to do more than produce a streak in the aqueous acetic acid used as the irrigating solvent in the first direction.

Changes taking place in the leaf after it falls from the tree lead to an increase in the more complex polyphenols at the expense of the low-molecular-weight species. In all the species tested the bulk of the polyphenols present in aqueous extracts of fallen leaves are of this condensed type; storage of the undried leaves leads ultimately to a marked decrease in the activity of the water extracts, and this decrease is accompanied by a decrease in the polyphenol content of the extract. Presumably continued enzymic oxidation ultimately leads to such a degree of condensation of the polyphenols that these are rendered largely insoluble in water.

If a leaf extract is allowed to percolate down a column of ferric oxide, and the rate of addition of the extract is not too great, the intensely coloured reaction products are retained in the column and a virtually iron-free and colourless effluent may be obtained for column loadings equivalent to several times the bed volume. The pH of a rimu leaf extract rose from 4·1 to 7·0 after passage through a column; no polyphenols could be detected in the effluent, and the amino acid content had been decreased very considerably. (C. Bloomfield.)

Effect of soil waterlogging

In the previous studies on waterlogged soils, the experimental conditions chosen were such that tendencies towards mobilization effects would be enhanced, and, conversely, any tendencies towards immobilization would be minimized. These investigations have now been extended to deal with systems more nearly approaching actual soil conditions, and with elements other than iron, to which most attention had previously been given.

Incubation of top-soil from an arable field (a heavy clay loam derived from London Clay) at moisture contents slightly above its water-holding capacity, converts iron and manganese oxides to

water soluble compounds. Addition of organic matter in the form of dried grass (either roots or aerial parts) increases the extent of mobilization. Leaching the incubated soil with molar ammonium acetate solution (pH 7) removes greater quantities of these elements than does water extraction, and for iron and manganese this disparity is considerable. A large proportion of the iron and manganese reaction products are thus sorbed on the soil colloids sufficiently strongly to resist leaching by water. An interesting feature of the water and ammonium acetate extraction curves is that while the former shows a fairly rapid initial rise, followed by a slow increase which continues throughout the rest of the incubation (*c.* 30 days), the ammonium acetate curve rises more steeply at first, and quickly reaches a constant value. In other words, the quantity of "fixed" iron or manganese is greatest in the early stages of the incubation, and decreases with time. This suggests that the initial solution/reduction of the iron and manganese compounds is quite rapid, since this point is presumably indicated by the point at which the ammonium acetate extraction curve becomes horizontal, but that further slower changes take place which result in decreased sorption of the reaction products.

For calcium and potassium, as would be expected, ammonium acetate extraction of the soil incubated without additional organic matter gives constant values from zero time throughout the incubation. Addition of grass, however, causes a decrease in the amount of calcium recovered by ammonium acetate extraction. Owing to the relatively small amount of calcium present in the soil, it will be necessary to repeat these experiments under conditions in which the effect of experimental error in the calcium determinations will be less important.

The effects of aeration and of drying on the incubated soil have also been studied. Both treatments cause rapid immobilization of the iron; the mount of manganese extracted by ammonium acetate is scarcely affected by aeration, but water-soluble manganese disappears after a time. In general, drying is more effective than aeration in causing immobilization. (J. W. O. Jeffery and C. Bloomfield.)

SOIL MICROBIOLOGY DEPARTMENT

P. S. Nutman

H. G. Thornton retired from the headship of the department on 1 October 1957. E. A. Peterson was awarded the Ph.D. degree of London University and returned to Ottawa in July. Mr. J. N. Parle arrived 1 September from Rukuhia Soil Research Station, New Zealand to work on the microbiology of the alimentary tract of soil animals and their excreta. R. Cooper joined the staff on 1 October to work on biochemical aspects of symbiotic nitrogen fixation. The following short-term visitors were also accommodated in the department during the year: J. Heidemeyer from the Technical University of Berlin to assist in chemical preparative work (6 months), I. B. Holland of Sheffield University for glasshouse work (6 weeks), H. D. L. Corby of the Grasslands Research Station, Marandellas, Southern Rhodesia (2 weeks), G. Muromtsev from the All Union Institute of Agricultural Microbiology, Moscow, for consultations and to learn techniques (6 weeks). F. A. Skinner attended the Society of Applied Bacteriologists symposium on the formation and germination of spores at the University of Leeds in July.

The work of the department has centred around two main topics: the ecology of soil micro-organisms and various aspects of the nitrogen cycle. In addition, work has continued on the chemistry and microbiology of the breakdown of chlorinated aromatic compounds in the soil and on anaerobic cellulose decomposition.

The free-living nitrogen-fixing bacteria (J. Meiklejohn)

Counts of Azotobacter on some of the Broadbalk plots were continued, and during the past season the following new results were obtained.

(i) Azotobacter numbers remained at a low level during the summer on the fallow section of plots receiving nitrogen (e.g., Plots 7, 10, 11 and 15); on the no-nitrogen plots 3 and 5 the numbers on the fallow section were rather higher. Plots 17 and 18, which receive nitrogen and minerals in alternate years, had more Azotobacter during fallow than any of the other plots sampled.

(ii) The sections carrying the first wheat crop after fallow all showed an increase in Azotobacter numbers through the winter, with a peak in spring or summer, which was most marked in those plots which had nitrogen.

(iii) During March and April 1957, the top half of section I of the field, which is now under continuous wheat cropping, began to show signs of nitrogen deficiency. Samples were taken from the top halves of two of the worst affected plots, 9 and 18; these were found to have 220 and 266 Azotobacter per gram of soil, whereas the lower halves of the same plots, carrying their first crop of wheat after fallow, had 440 and 499 Azotobacter per gram respectively.

Counts have been made on some grass fields; the grass half of Broadbalk Wilderness has a large Azotobacter population, but the new grass on the irrigation experiment at Woburn had none when a count was made in the spring, and very few in the autumn; it is proposed to continue these counts to see if the Azotobacter population will build up.

Work has continued, so far without success, to develop a better method of counting nitrogen-fixing anaerobes in soil.

The nitrifying bacteria (J. Meiklejohn and N. Walker)

It is now possible to obtain in about 10 days in a clear medium which permits good growth, a Nitrosomonas culture which can be used for physiological studies. It was found that sodium bicarbonate could replace calcium carbonate as a source of CO_2, and the number of trace elements in the medium has been reduced to five without disadvantage. Organisms grown in this medium were active in oxidizing ammonia or hydroxylamine to nitrite in Warburg respirometers. It is hoped to improve the medium still more, so that it can be used in a continuous culture apparatus.

Cultures of Nitrobacter are in process of being purified, and when this is done the best medium for them will be worked out.

Studies in symbiotic nitrogen fixation (P. S. Nutman)

Work has been resumed, after an interval of 3 years, on the genetics of symbiotic nitrogen fixation in red clover. Selection and breeding work is in progress with a number of pedigrees containing new types of segregant which are defective in fixing nitrogen in association with a normal effective strain of bacteria.

In connection with studies on root-hair infection, detailed below, twelve very small seeded species of *Trifolium* and two of *Lotus* have been grown for seed and opportunity taken to determine their symbiotic responses with four strains of bacteria. The results indicate that all the species of *Trifolium* fall into one or other of the three major groups of response proposed by Vincent. Also included in current tests were two ecotypes of *Trifolium ambiguum* and strains of nodule bacteria from the Caucasus sent through the kind offices of A. Imschimski. These hosts were shown to respond more effectively with *Rh. trifolii* of Turkish origin than with the local strains. With all strains a proportion of plants of both ecotypes failed to nodulate.

The initial infection of the clover root by nodule bacteria (P. S. Nutman)

The work, earlier reported, has been extended to include all the small seeded species mentioned above, in each of which early infection has been shown to take place in two distinct phases. In the first the number of infected hairs increase at a rapid rate; in the second the increase is negligible. More detailed study with the most suitable species from the observational point of view (viz., *Trifolium repens* and *T. fragiferum*) has disclosed that the increase in number of infected root hairs is exponential in both phases, the ratio of the indices to the exponential ($\log_{10}$ number infection/hour) changing from about 0·021 to 0·00045, the change in rate occurring at the time the first nodule is produced. Work is in progress to determine

the influence of bacterial strain upon infection rate, after which the study will be developed along experimental lines to elucidate the physiology of the early stages of infection.

The routes of infection in hosts of the Cowpea cross-inoculation group (A. H. Gibson)

Infection by avenues other than the root hair has been recorded for some members of the cowpea cross-inoculation group. These and other species are being reinvestigated by serial microtomy to determine the mode of infection, the site of nodule initiation and nodule development. Preliminary results are summarized in the following table. Data for a member of the *Trifolium* cross-inoculation group are included for comparison.

Species	Presence of infected root hairs	Nodule position *	Site of nodule initiation	Mode of spread of bacteria in nodule tissue
Aeshynoneme americana	+?	Mostly A	Outer cortex of young lateral roots	Cell division
Crotalaria brownii	—	A and R	Outer cortex	Cell division
Desmodium nicaraguensis	+	Mostly R	Outer cortex	Cell division and inf. threads
Desmodium ovalifolium	+	A and R	Outer cortex	Cell division and inf. threads
Dichrostachys spicata	+	Mostly R	Outer cortex	Cell division
Indigofera endecaphylla	+	A and R	Outer cortex	Cell division and inf. threads
Stylosanthes gracilis	.	Mostly A	.	Cell division only?
Trifolium subterraneum	+	A and R	Inner cortex	Infection thread

* A, axilliary position at the point of emergence of a lateral root. R, elsewhere on main or lateral roots.

The stimulation of infection by root secretions (A. H. Gibson)

The extension of work in this field has been hampered by the failure to obtain reproducible results. This has been shown to be due partly to the environment. The time at which the first nodules appear on the roots is correlated both with the sunlight in the previous 24–48-hour period and the minimum temperature in the preceding 24 hours. Further analysis of the effect of root secretion will require controlled environment facilities.

The co-existence of Rhizobium trifolii and its bacteriophage in artificial soil mixtures (J. Kleczkowski)

Bacteriophage active against *Rh. trifolii* occurs in all soils in which the host plant has been grown for more than one season, and the clover nodule bacterial themselves are present in all normal soils in the United Kingdom. It is necessary therefore first to free soil of phage and its host bacteria before experimental work on their interrelations can be undertaken in soil. This has not been found possible without seriously affecting the soil, so that recourse has been made to an artificial soil of sand and vermiculite to which was added dilute soil extract or Demolon and Dunez medium.

Effective and ineffective strains of clover nodule bacteria with their corresponding phages were inoculated into artificial soil and the phage and bacteria assayed over the following three months. Immediately after inoculation the phage increased and the bacterial numbers dropped. At about 2 weeks phage-resistant bacteria appeared and increased until an equilibrium was established.

At 6 weeks and at the end of the experiment the phage and bacteria were re-isolated and examined.

A proportion of the phage isolates were found to have changed in plaque type during storage in artificial soil. These changes were temporary, the normal plaque form reappearing after five or six bacterial passages.

A large number of bacteria isolated after storage in presence of phage differed from original strains in phage-resistance and in symbiotic properties. The ineffective strain "Coryn" gave rise to variants which were partly effective; some host plants inoculated with them responding effectively and others ineffectively. Repeated re-isolation from either type of responding host failed to stabilize the strain's symbiotic properties. As reported earlier, the effective strains gave rise to ineffective mutants which were stable. Further work will be directed towards elucidating the nature of the changes in phage and bacteria.

The streptomycin-resistant bacteria of the rhizosphere (M. E. Brown)

Studies on the stimulation of streptomycin-resistant bacteria in the rhizosphere of clover plants have continued. This stimulation was confirmed in the rhizosphere of nine other leguminous species; and was absent in the rhizospheres of nine non-leguminous plants. Leguminous stimulation occurred in each of the four soil types tested.

The following substances were added to the soil in an attempt to reproduce the stimulation: four amino-acids, either singly or in various combinations, two growth factors, six nucleic acid derivatives and three sugars. Of these only two nucleic acid derivatives, guanine and guanosine, and two sugars, laevulose and ribose, consistently increased numbers of streptomycin-resistant bacteria.

Experiments with root exudate gave inconsistent results, and further work is in progress to improve the method of collecting root exudate.

The possibility that the increase in streptomycin-resistant bacteria may be the result of a stimulation of actinomycetes in the rhizosphere was studied. A number of actinomycetes were isolated both from the soil and the rhizosphere and tested by the streak method against resistant and non-resistant bacteria from the rhizosphere and from the soil. The actinomycetes had no effect on the streptomycin-resistant bacteria, but antagonized all the non-streptomycin-resistant bacteria, indicating a possible connection and interaction between the two groups of organisms. It was found, however, that substances which stimulated the actinomycetes in the soil did not also stimulate the resistant bacteria, and substances stimulating the bacteria did not stimulate the actinomycetes.

Life-cycle of Nocardia in soil (M. E. Brown)

The study of the life-cycle of *Nocardia cellulans* in the soil was completed. Experiments were made in partially and totally sterilized and in untreated soil. In partially sterilized soil wide fluctuations in numbers of *Nocardia* occurred during the first month following inoculation of the soil with a pure culture of *Nocardia cellulans*. These fluctuations became less marked, and at the end of a year the *Nocardia* was still present in high numbers. The numbers of bacteria in such a soil were depressed in comparison with uninoculated control. *Nocardia* disappeared from the untreated soil in 6 months. The wide fluctuations in numbers in partially sterilized soil were correlated with a regular alternation between the rod and mycelial forms of *Nocardia*. Peak counts corresponded to the rod form and troughs to the mycelial form and the steadying in count to the rod form. On an agar medium the organism went from the rod stage to the mycelial stage and then back to the rod, staying in this last form until re-inoculated on to a fresh medium.

Fungistasis in soil (R. M. Jackson)

The effect of pH on the fungistatic activity of soil has been studied in Park Grass plots. A close correlation between soil pH and fungistasis was found; least inhibition of germination of the test fungus was produced by soil from the more acid plots and most inhibition by the less acid plots.

The evidence obtained from soil sterilization experiments strongly suggests that aerobic spore-forming bacteria may be responsible for natural soil fungistasis. Examination of two series of spore-formers isolated from pasteurized soil showed that while twenty-one out of twenty-three of the *Bacillus mycoides* type isolates inhibited germination of the test fungus on agar plates, only fourteen out of seventy-eight of the other isolates had a similar effect. The cell-free filtrate of cultures of one of the *B. mycoides* isolates produced a spectrum of inhibition of the test series of fungi similar to that of fresh soil.

Two techniques have been used to study the interaction of soil fungistasis and the rhizosphere effect. In the first, glass plates were coated with a fungal-spore suspension in agar and buried at an angle of 45° beneath germinating seeds. The plates were removed at intervals and the effects of the seedling roots which had grown into contact with the plates observed. In the other method direct observations with the Leitz Ultropak were made upon the behaviour of fungal spores in contact with fresh soil through which seedling roots were growing in small glass cells. Pea roots stimulated the germination of inhibited conidia of *Gliocladium roseum* and *Paecilomyces marquandii* and also chlamydospores of a species of *Fusarium*, the formation of which had been induced by soil. The germ tubes of *G. roseum* and the *Fusarium* showed a pronounced tropic growth towards the roots. In experiments with radish seedlings, germination of conidia of *G. roseum* and *P. marquandii* in the rhizosphere was observed to be followed by a period of vegetative growth and finally sporulation. Efforts are now being made to

obtain root exudates which show activity in counteracting soil fungistasis.

Bacterial decomposition of herbicides (N. Walker and T. I. Steenson)

Work on the persistence of herbicide-decomposing micro-organisms in soil, carried out in collaboration with Messrs Sutton & Sons, has been completed and the results published.

The adaptation of bacteria to oxidize 2 : 4-D and MCPA has been studied further. It has been shown that adapted organisms may be obtained by growth on peptone agar containing a suitable concentration of the substance to be studied; it is not essential therefore for the herbicide to be the main source of carbon in the medium. Because of this finding, it was possible to examine the effects of related compounds on adaptation, irrespective of whether they were metabolized by the bacteria or not. By growing *Flavobacterium peregrinum* in presence of MCPA or the isomeric 2-chloro-4-methylphenoxyacetic acid, organisms were obtained which were adapted to oxidize 2 : 4-D, but not MCPA. Various related compounds did not induce adaptation to 2 : 4-D. Growth of bacteria in presence of 2 : 4-dichlorophenol or 5-chloro-2-cresol caused adaptation to these two phenols, but not to 2 : 4-D nor to MCPA.

The isolation of anaerobic cellulose-decomposing organisms (F. A. Skinner)

The anaerobic cellulose-decomposing bacteria from soils and organic wastes are responsible for the initial stages of the bacterial degradation of cellulose, a process which results finally in the production of gas rich in methane. The investigation this year has been concerned mainly with the improvement of techniques for isolation.

The original technique, similar to that used by other workers for isolating anaerobic cellulolytic bacteria from the rumen of herbivores, involved the preparation of a sterile reduced medium which is transferred aseptically and without ingress of air to the culture vessels. Satisfactory cultures were rarely obtained by this method. An improved method which has been devised consists of preparing the medium, in a specially stoppered flask, boiling to expel air and passing in oxygen-free nitrogen both before and after the addition of a reducing agent such as cysteine hydrochloride. With a movable spring-loaded delivery tube, fully reduced medium can be transferred without admitting air, to small screw-capped culture bottles. After filling, caps are screwed on tightly and the sealed bottles sterilized. When a bottle is opened for inoculation or sampling, it is flushed with sterile nitrogen. With this technique and the McIntosh and Fildes jar, a pure culture of a spore-forming cellulose-decomposing bacterium was obtained, and its characteristics are being studied. A low concentration of yeast extract provides all the accessory factors necessary for fairly rapid growth in liquid medium. Several contaminant species of bacteria isolated from impure cultures have been tested with the cellulose-decomposing isolate, none of which has any stimulating effect on the isolate's growth or cellulolytic power. Growth in cellulose–agar is very slow. Possible reasons for this are poor dispersion of cellulose particles,

the need for more strongly reducing conditions, or presence of inhibitors in the agar. Studies have continued on the ability of sodium carboxymethyl cellulose to prevent flocculation of the cellulose particles in agar media, and on the oxidation–reduction potentials developed by different reducing agents.

Enrichment cultures of anaerobic bacteria capable of converting various organic compounds to methane have been prepared, and the purification of these strains is in progress.

BOTANY DEPARTMENT

D. J. Watson

Dr. Katherine Warington retired on 30 September; she had been a member of the staff since 1921.

P. J. Welbank and A. W. Wheeler joined the department in October, and G. H. King transferred to the Plant Pathology Department, but has continued to supervise the Botany glasshouses.

Gillian N. Thorne was awarded a Post-Doctorate Fellowship by the National Research Council of Canada, and went to Ottawa in November to spend a year in the Botany and Plant Pathology Laboratory of Science Service, Department of Agriculture.

Joan M. Thurston prepared the material for an exhibit for the Chelsea Show of the Royal Horticultural Society in May, illustrating factors that affect the multiplication and spread of weeds.

D. J. Watson contributed a paper to a symposium on the Biological Productivity of Britain, organized by the Institute of Biology, and held in London in October.

A large Dutch-light glasshouse was erected early in the year, to enable work on effects of soil-moisture content on crop growth to be done independently of rainfall, with the whole water supply controlled by irrigation.

Plant Nutrition

Chelated iron complexes as sources of iron in solution culture (K. Warington)

Chelated complexes of iron with the following compounds were tested as sources of iron in solution cultures of peas and soybeans:

(*a*) mono-sodium ethylenediamine tetra-acetate, EDTA (Na);
(*b*) hydroxyethyl ethylenediamine triacetic acid, HEEDTA;
(*c*) diethylenetriamine penta-acetic acid, DTPA;
(*d*) ethylenediamine NN′bis (hydroxyphenyl acetic acid), CHEL 138.

(*a*), (*b*) and (*c*) were the most effective of a large number of compounds tested previously (*Rep. Rothamst. exp. Sta. for* **1956**, p. 77), and all were superior to ferric citrate; (*d*) was not previously available. All the compounds were kindly supplied by the Geigy Company Ltd. When they were added in a range of concentrations from 0·06 to 1·0 p.p.m. Fe to a nutrient solution with an initial pH of 5·5, the development of iron-deficiency symptoms in the shoots of peas (apical chlorosis and crinkling of the leaves) was prevented by 0·125 p.p.m. Fe supplied as (*d*), but 0·25 p.p.m. Fe was required if supplied as (*a*), (*b*) or (*c*). With soybeans also, (*d*) was about twice as effective as the other compounds; 0·5 p.p.m. Fe as (*d*) prevented the appearance of iron-deficiency symptoms compared with 1 p.p.m. Fe required in the other forms. Averaging all rates of supply,

plants that received (*d*) had a higher dry weight than the others. In a second series of tests comparing nutrient solutions with initial pH of 5·5 or 7·5, (*d*) was equally effective in suppressing deficiency symptoms at either pH, but the other complexes were less effective in the alkaline than in the acid solution. The shoots of plants that received (*d*) usually had a slightly higher iron content than those of plants that received equivalent iron in a different form, but the roots had a much lower iron content. This is in keeping with the greater effect of (*d*) on shoot symptoms, because accumulation of iron in the roots is usually associated with iron-deficiency chlorosis of the shoots. (*c*) also decreased the iron content of the roots, but to a less extent than (*d*).

Nutrient uptake by excised roots (E. C. Humphries)

Chemical analyses were completed on material from pot experiments on barley and potatoes, designed to test whether variations in nutrient absorption or loss by excised roots can be used to measure soil deficiencies in the sense that they are correlated with responses to added nutrients (*Rep. Rothamst. exp. Sta. for* **1956**, p. 78). Roots from plants grown with all combinations of three levels of nitrogen, phosphorus and potassium were excised 7–8 weeks after planting and transferred to a complete nutrient solution in standard conditions. Contrary to previous experience, nearly all the excised root samples absorbed nutrients from the standard solution, even if they came from plants which had received adequate nutrient supply; in earlier experiments roots from such plants lost nutrients to the solution. It was therefore not possible to diagnose nutrient deficiencies simply by measuring gain or loss of ions by the excised roots. The relation between uptake by excised roots and the nutrient status of the plants from which they came is evidently a complex one, and is still being investigated.

Effect of boron on production of adventitious roots (E. C. Humphries)

Some further experiments were done on the effect of applying boron, with or without carbohydrate, to the primary leaves of dwarf French beans (*Phaseolus vulgaris*) on the formation of adventitious roots by the hypocotyl (*Rep. Rothamst. exp. Sta. for* **1955**, p. 79). They confirmed that sucrose applied in the light, but not in the dark, depressed root formation, but fructose and glucose in the same concentration had no effect. An organic boron compound (phenylboronic acid) was as effective in producing roots as sodium borate in solutions supplying equivalent boron. As reported previously, no interaction was found between boron and sucrose, so there is no evidence that boron accelerated sucrose transfer to the hypocotyl.

Effect of time of application of nitrogenous fertilizer to wheat (G. N. Thorne)

Field experiments on wheat have shown that, on the average, late nitrogenous top-dressings are as effective as early top-dressings in increasing grain yield, but in pot experiments (*Rep. Rothamst. exp. Sta. for* **1955**, p. 76) late applications of N were much less effective than early applications. The explanation suggested was that the

plants grown in pots had such a low N-supply from the soil that they were incapable of responding to a late application of nitrogenous fertilizer. This implies that the response in grain yield to late N increases with increase in the supply of N available early in growth, at least over some part of its range. To test this, wheat was grown in soil in pots with 0, 0·5 or 1·0 g. N per pot applied in mid-March, and in addition, some plants had 0·5 g. N applied either in mid-March or at the time of ear emergence in late May.

Contrary to the hypothesis, the response in grain yield to the additional 0·5 g. N per pot applied late, like that to an additional early application, decreased with increase in the basal N supply in March. The response in number of ears also was smaller when the basal N supply was increased, and was similar for both times of application. Evidently further work will be necessary to explain the discrepancy between the field and pot results. With the lowest basal rate, additional late nitrogen increased grain yield mainly by increasing the number of ears, whereas at the higher basal rates the extra grain yield was produced mainly by ears already present when the late N was applied.

Growth Studies

Effect of excising roots on shoot growth of barley (E. C. Humphries)

Experiments on the effect of removing all or part of the root systems of barley, rye or tomato plants on growth in subsequent short periods have been reported previously (*Rep. Rothamst. exp. Sta. for* **1956**, p. 79). The barley experiments have been extended to measure effects on subsequent growth to maturity of removing at successive dates the whole root systems of plants grown in solution culture. When the roots were removed 40–50 days after germination while shoot number was still increasing, the number of ears produced was increased by more than 10 per cent. Later removal of roots, after shoot number had reached its maximum, had no effect on ear production. It is suggested that the increased ear number is attributable to a temporary diversion to the shoots and developing ears of carbohydrate that would otherwise be used in root growth. Root removal made little difference to the final nitrogen content of the shoot, and data for other nutrients are not available. High temperatures in the glasshouse at the time of anthesis caused very erratic grain formation, but the total plant dry weight at harvest was unaffected by removal of the roots, except that it was decreased a little when the roots were excised at the last date, near to ear emergence.

Effect of gibberellic acid and kinetin on leaf growth and net assimilation rate (E. C. Humphries)

Gibberellic acid has been shown by other workers to increase the leaf area of some plants, and an experiment was done to measure its effects on leaf growth of potato and to determine whether it alters the efficiency of the leaves in dry matter production. Kinetin (6 furfuryl-amino-purine), a growth substance that is said to affect cell division, was tested in the same experiment. Potato plants grown from small sets, each with a single eye, were sprayed at the stage when they had eleven leaves on the main shoot and no

lateral branches with gibberellic acid (50 p.p.m. in water), kinetin (0·025 p.p.m.), or both, or distilled water. The spraying was repeated a week later. When half the plants were harvested after two weeks, gibberellic acid had increased the leaf area of the main shoot by 36 per cent and of the lateral branches by 65 per cent, without altering the number of leaves. When the remaining plants were harvested after 2 more weeks the increase by gibberellic acid in leaf area of the main shoot still persisted, but the effect on the lateral branches had disappeared. Kinetin had no immediate effect on leaf area, but decreased it at the second harvest. At the first harvest, gibberellic acid had not affected total plant dry weight but had altered its distribution so that the weight of stem and leaves was increased and that of tubers decreased; the weight of roots was unchanged. At the second harvest the dry weight of stem and leaf was unaffected by the gibberellic acid treatment, but the weight of tubers was increased. Kinetin alone depressed the tuber weight, but not in the presence of gibberellic acid. The number of tubers was increased by gibberellic acid, and the tubers were longer and thinner than those of control plants, and had conspicuous scale leaves. The mean net assimilation rate for the interval between the two harvests was only slightly reduced by gibberellic acid. In the experimental period, therefore, the enlarged leaf area of plants treated with gibberellic acid had a photosynthetic efficiency nearly as great as that of untreated plants, and consequently the treated plants produced a higher dry-matter yield. As there were indications at the end of the experiment that the leaf area of plants sprayed with gibberellic acid was declining more rapidly than that of unsprayed plants, it is possible that the increase in dry-matter production caused by gibberellic acid would not persist in plants grown to maturity.

In experiments on dwarf French bean plants gibberellic acid increased the rate of expansion of leaves but not their ultimate size. Leaves sprayed with gibberellic acid wilted readily, and sometimes did not recover. Kinetin had a depressing effect on leaf growth, which was counteracted by gibberellic acid, as in the potato experiments. The depression by kinetin occurred only when the plants were placed in darkness immediately after spraying, but this result needs confirmation.

Effects of mineral nutrients on leaf growth (L. H. Fernando)

Experiments on sugar beet started in 1956 (*Rep. Rothamst. exp. Sta. for* **1956**, p. 86) to analyse the effects of the major plant nutrients on leaf area per plant, with particular reference to the stage of growth at which the effects appear, were continued and repeated on potatoes. The plants were grown in pots in a deficient soil without fertilizer, or with addition of nitrogen, phosphorus and potassium separately and in all combinations. Counts were made at intervals of the number of leaves present and the number dead, from which the rate of leaf production and the length of life of leaves was determined, and the areas of individual leaves were measured.

The effect of phosphorus in increasing the leaf area of sugar-beet plants was maximal about 6 weeks after germination; it then declined but persisted to the end of the experiment. Nitrogen had no

effect on leaf area per plant during the first 6 weeks, but later caused a large increase which was maximal after 12 weeks. Potassium had much less influence on leaf area per plant than the other nutrients in these experiments; like nitrogen, it was most effective at about the 12th week. There were positive interactions between the nutrients; each had a greater effect in the presence of the others.

Phosphorus increased the rate of production of new leaves throughout the growth period, but its effect decreased with time. Nitrogen did not alter the rate of leaf production during the first two months, but later increased it, while potassium had no effect at any time.

On the average of all treatments the longevity of successive leaves increased steadily from the first to the fifteenth; leaves after the fifteenth were still alive at the end of the experiment, so their full functional duration could not be determined. Nitrogen increased the longevity of the first six leaves by 1–7 days, but shortened the life of later leaves by longer periods, up to 4 weeks for leaf 12. Potassium had only small effects that tended to increase in the later leaves, which showed severe deficiency symptoms in plants that received no potassium. It extended the life of the 15th leaf by about 1 week.

The final size of successive leaves in the age series increased to a maximum and then decreased. Phosphorus increased the size of the first ten leaves, but decreased that of subsequent ones. Nitrogen consistently increased leaf size with a maximal effect in leaves 10–20. Because of these changes, the largest leaf occurred earlier in the series when phosphorus was applied, and was delayed to a later leaf by nitrogen application. Potassium caused a small increase in the first fifteen leaves, but not subsequently.

The increase in leaf area per plant caused by phosphorus in the early stages of growth was thus attributable to a combination of more rapid production, longer survival and larger size of leaves near the beginning of the age series. At a later stage the higher number of leaves on plants that received phosphorus was offset by smaller leaf size. The effect of nitrogen was attributable to increases in both the size and number of leaves; the higher rate of leaf production was more than sufficient to counterbalance more rapid death of leaves. The increase in leaf area per plant caused by potassium was at first wholly attributable to greater leaf expansion, but later it was caused by longer survival of leaves.

Similar effects were found for potato, but the nitrogen response occurred earlier, and the effects of potassium were relatively greater than with sugar beet.

Interdependence of leaves (L. H. Fernando)

The expanding leaves of a plant presumably compete for mineral nutrients absorbed by the roots, and for water if the supply is restricted. Also, carbon compounds necessary for their growth, in the early stages at least, may be provided by photosynthesis in older leaves. Thus the growth of a particular leaf is likely to be dependent on the activities of the other leaves. An investigation of the interdependence of leaves produced from the same apical meristem was begun in 1956 (*Rep. Rothamst. exp. Sta. for* 1956,

p. 87) on sugar beet and tobacco plants. The sixth leaf was selected as the chief test object, but the growth of other leaves was also measured. Some plants had some or all of the first five leaves removed at the time when the sixth leaf was beginning to expand, and on other plants leaves 7–11, or all the leaves after the sixth, were cut off in succession as they appeared. Undefoliated plants were kept as controls.

The size of the sixth leaf of sugar-beet plants with a low nutrient supply was increased by removing the first five leaves, but the same treatment decreased the size of the sixth leaf of plants with a high nutrient supply. On plants from which leaves 1–5 were removed the sixth leaf died sooner than on undefoliated plants. Removal of leaves 3–5 had similar but smaller effects on leaf 6. The growth of many leaves produced after the sixth was affected by removal of leaves 1–5 in a similar way to that of the sixth leaf.

Removal of leaves 7–11 consistently increased the size of leaf 6, and also of leaves produced subsequently to the eleventh. When no leaves were allowed to develop after the sixth the first six leaves grew larger, and survived and continued to expand for a longer period.

Similar results were obtained with tobacco, except that loss of leaves 1–5 had no effect on the growth of leaf 6, but decreased the size of subsequent leaves with a maximal effect at leaf 10.

In another experiment the same defoliation treatments were applied to plants with varied supply of nitrogen, phosphorus and potassium to find out which of the major nutrients was involved in the interaction with the effect of removing leaves 1–5. Chemical analyses are being made on material from this experiment to determine whether the effects of defoliation on leaf growth can be related to changes in mineral content of the leaves, and in the distribution of nutrients between leaves, but these are not yet complete.

Varietal differences in barley (G. N. Thorne)

Although Plumage Archer barley produces more tillers than Proctor, a smaller proportion survive to form ears, so that Proctor has more ears at harvest (*Rep. Rothamst. exp. Sta. for* **1956**, p. 83). This fact is probably significant in relation to yield, because the higher grain yield of Proctor in field cultures has been shown to result from additional photosynthesis in the ears. The causes of this difference in tiller survival were investigated in several experiments. In one of them the two varieties were grown in soil in pots with or without additional nitrogen, and each tiller was labelled as it appeared. At fortnightly intervals pots were harvested, the plants dissected and the stage of development of the apical meristem of each shoot was determined. All the main shoots survived to form ears. In plants that received no nitrogenous fertilizer, about half the first primary tillers of both varieties survived; almost all the second primary tillers of Proctor also survived, but none of Plumage Archer. At the higher rate of N supply nearly all the first and second primary tillers survived for both varieties, and the varietal difference occurred in the secondary tillers; 85 per cent of those produced by Proctor survived, but only 14 per cent in Plumage Archer. These results suggest that in Proctor there was a relaxation

of apical dominance compared with Plumage Archer, rather than a general change in the ability of tillers to survive.

Death of tillers usually occurred shortly before ear emergence, and at earlier harvests no differences in development were detected between apices of shoots destined to survive to maturity or to die without producing an ear, in comparisons either between or within varieties. The dry weight and leaf area of each shoot were also determined, and the samples kept for nitrogen estimation, but these results are not yet complete. The survival of a larger proportion of shoots of Proctor was associated with a higher ear : shoot dry weight ratio at the time of ear emergence.

Another experiment tested the effect of removing ears from some older shoots on the survival of the rest. Shortly before the ears emerged, or two weeks later, ears on the main stem and the first two primary tillers of Plumage Archer and Proctor plants were cut off. To determine whether the apices of the older shoots influence the development of lateral shoots by auxin production, as in vegetative shoots, lanolin paste containing 100 p.p.m. IAA was placed on the cut ends of the shoots in half of the pots from which ears were removed.

Removing ears on the first occasion increased the number of ears at harvest in both varieties, but more for Proctor than Plumage Archer. However, this increase was entirely due to production of more tillers after the ears were removed; the survival of shoots already present at that time was unaffected. Removal of ears on the second occasion, or auxin application at either time, did not influence the production or survival of tillers. Removing ears had no effect on the dry weight of the treated shoots, but increased the dry weight and grain yield of the other shoots. Auxin had no effect on shoot dry weight, but grain yield was apparently decreased by the first auxin application and increased by the second.

An attempt was made to determine how the shoots of a barley plant influence each other's survival, by comparing the behaviour of intact plants grown in solution culture with that of plants divided up into their constituent shoots and returned to grow in the same vessels as the intact plants, but unfortunately this gave erratic results, and needs to be repeated with an improved technique.

Effect of varying soil moisture deficit on plant growth (P. C. Owen)

Previous work has shown that pot cultures are unsatisfactory for studying effects of soil water supply on plant growth, because conditions of water stress can be maintained only for short periods compared with what occurs in the field (*Rep. Rothamst. exp. Sta. for* **1956**, p. 85). Instead of pot cultures, small field plots protected from rain by a Dutch-light structure so that the whole water supply was under control were therefore used for a continuation of this investigation. Sugar-beet were grown with uniform watering until the beginning of June. Then the soil water content on all plots was brought to field capacity (about 28 per cent water) and three treatments were compared:

(*a*) Minimal water stress, with the water content of the soil maintained near field capacity by frequent watering; a total of 5·4 inches of water was applied.

(*b*) The mean soil water content to a depth of 12 inches was allowed to fall to 13 per cent in early July; this is a little above permanent wilting percentage (about 10 per cent for this soil); it was then restored nearly to field capacity by a single application of 1 inch of water, and subsequently allowed to fall steadily to 14 per cent in August.

(*c*) Five waterings, totalling 1 inch, were given at intervals in July and August; the water content varied between 12 and 20 per cent.

The large expenditure of water needed for treatment (*a*) gave a high yield, over 6 tons total dry matter per acre by late August. When only 1 inch of water was applied in treatments (*b*) and (*c*) the total dry-matter production was less, but was still 80 per cent of that on the heavily watered plots. This contrasts with the result of the pot cultures—in which short-period fluctuations over a similar range of water potential had no effect on growth or yield. Plants receiving treatment (*a*) had a higher leaf area than the others throughout, and this accounted almost entirely for the greater dry-matter production, because net assimilation rate was only slightly affected, though immediately after the water applications in treatments (*b*) and (*c*) it was consistently a little higher than for treatment (*a*). This was similar to, but much less than, the effect of a small amount of rain on the net assimilation rate of an unirrigated crop following prolonged drought reported previously (*Rep. Rothamst. exp. Sta. for* **1955**, p. 77), and in spite of it the rate of dry-matter production after the waterings of treatments (*b*) and (*c*) was always less than for treatment (*a*). Contrary to present horticultural opinion, small frequent applications of water (treatment (*c*)) gave a slightly higher yield than the same amount given in one large application (treatment (*b*)).

Dependence of net assimilation rate of barley on leaf-area index (D. J. Watson and S. A. W. French)

The net assimilation rate (E) of thousand-headed kale decreases rapidly with increase of leaf area index (leaf area per unit area of land; L) presumably because mutual shading of leaves becomes more intense (273). Consequently, the crop growth rate (rate of dry-matter production per unit area of land; C) reaches its maximum when L is comparatively small, between 3 and 4, and decreases with further increase of L. Values of L well above the optimum, between 5 and 6, were found in the later stages of growth of the kale crops used for the experiments. For sugar beet, E decreases less rapidly with increase of L than for kale, and so maximum C was not attained within the range of L tested, up to 6, but may be within the range on very fertile soils, as in the Fens, where sugar beet have very large tops.

Experiments were done on barley to test whether there is a similar dependence of E and C on L for cereals, which differ greatly from kale and sugar beet in size, shape and distribution of leaves. In the kale and sugar-beet experiments, L was varied by removing different fractions of the plant population, by pulling up individual plants distributed in a systematic pattern through the crop. This

was not possible in a barley crop, because plants cannot be distinguished except in the early stages of growth, and instead L was varied by removing either whole rows of crop, or 1-foot lengths distributed systematically along the rows; the two methods gave the same results. From different plots, 0, $\frac{1}{4}$, $\frac{1}{2}$ or $\frac{3}{4}$ of the plants were removed in this way, and from their dry weights and leaf areas, the dry weights and leaf-area indices of the plants remaining on the plots were estimated. After a fortnight, the remaining plants were harvested, and E and C were calculated for each plot from the initial and final dry weights and leaf areas. Leaf sheaths were included in the measurements of leaf areas as well as laminae, and on this basis L for the unthinned crop in the second experiment was about 9.

E decreased nearly linearly with increase of L throughout the range from 2 to 9. The rate of decrease of E per unit increase in L, expressed as a percentage of the value of E for $L = 1$ obtained by extrapolation, was 6·9 per cent in the first experiment and 7·2 per cent in the second. The comparable average values previously found for kale and sugar beet were 16 and 6 per cent respectively. Thus, E for barley was affected by increase in L to about the same extent as that of sugar beet, and much less than that of kale. Maximal C for barley occurred when L was about 8 or 9, near the upper limit of the experimental range. The results confirm the previous conclusion that there is little if any scope for increasing total yield of dry matter by increase in L at its maximum, and that improvement in yield depends rather on increasing L at the times in the growth period when it is small. But the grain yield of cereals depends on photosynthesis after ear emergence, when L has declined from its maximum, and it may be possible to improve grain yield still further by increase in L at this time.

Photosynthesis of leaves at different levels in a crop (D. J. Watson and S. A. W. French)

The lower leaves of a crop are shaded by those above, and so should be less effective in photosynthesis than the upper leaves that are fully exposed to sunlight. Also the fall in rate of photosynthesis from the top to the bottom leaves of a crop should be greater when the leaf-area index (L) is higher, because mutual shading of leaves should be more severe, and this may explain the fall in mean net assimilation rate (E) of the whole crop with increase in L.

An attempt was made to measure differences in rate of photosynthesis between groups of leaves at different levels in a kale crop, by comparing the dry-matter production in a period of 2 weeks by unit area of intact crop having an average of eleven leaves per plant with that by crops from which either the four lowest leaves or the seven lowest leaves of every plant were removed. These defoliation treatments were applied both to unthinned plots and to plots from which alternate plants had been removed before the experiment began; the initial values of L for these were about 5 and 2·5 respectively.

Removal of the four lowest leaves decreased the leaf area of the plants by 40 per cent, but decreased dry matter production per unit area of crop by only 13 per cent. Similarly, the seven lowest

leaves, which represented 71 per cent of the leaf area, accounted for only 34 per cent of the dry-matter production. The mean net assimilation rates for the three groups of leaves at different levels of the crop in g./sq. m. of leaf area per week, were: four lowest leaves, 23; three middle leaves, 48; upper leaves (usually four), 112. Unfortunately, the experiment was not sufficiently precise to detect differences in the effects of defoliation between the crops with high and low L, but the results suggest that the reduction of E by increase in L occurred in leaves at all levels. As the lower leaves are older than the upper leaves, the difference between them in E may be partly an effect of ageing.

Measurement of leaf area (P. C. Owen)

A method for constructing a measuring grid from which the areas of elliptical leaves may be read directly, described by Freeman and Bolas (*Rep. East Malling. Res. Sta. for* **1955**, p. 104), has been modified so that leaves which have irregular geometric shapes, and which may be asymmetrical about one axis, can be measured. A grid based on slightly different principles is being developed for the measurement of the leaf areas of cereal crops and grasses.

Weed Studies

Wild oats (J. M. Thurston)

In the experiment on survival of wild oats seeds in a cultivated soil (*Rep. Rothamst. exp. Sta. for* **1956**, p. 80) only two more seedlings of *Avena fatua* appeared in 1957, and none of *A. ludoviciana*. The number of seedlings recorded in all the years of the experiment accounts for only about 20 per cent of the seeds sown in October 1950. Soil samples representing in all 60 sq. ft. of land to ploughing depth were taken in September 1957 and washed through sieves to see whether any viable but dormant seeds remained. Only two were found, both third seeds of spikelets of *A. fatua*, out of 3,000 sown. Evidently the 80 per cent of sown seeds, not accounted for as seedlings, are no longer present in the soil, but have been destroyed probably mainly by rotting, though some are known to have been taken by birds in the early years. The experiment has now been terminated.

The number of seeds of *A. fatua* that germinated in 1957, on plots ploughed in autumn 1956 out of temporary ley established in spring 1955 on an infested site at Rothamsted, was about the same as that found in 1956, on plots ploughed in autumn 1955; the large decrease that occurred in the first year under ley did not continue in the second year. This agrees with results previously found for a much heavier mixed infestation of *A. fatua* and *A. ludoviciana* in a field in Northamptonshire which showed that the infestation decreased more rapidly in the early years than later. The number of seeds recovered by washing through sieves from soil samples taken from the Northamptonshire field in 1957 was slightly less than in 1956, but over 4 million seeds per acre still remained after 4 years under ley, compared with about 15 million per acre in 1954, when the first counts were made after 1 year under ley.

A study of the development of seeds of *A. ludoviciana* at different positions in the panicle (*Rep. Rothamst. exp. Sta. for* **1956**, p. 51)

was continued and showed that many seeds were fully developed and already dormant 15 days after anthesis. The percentages of viable and dormant seeds increased between the 15th and 25th days. The percentage of non-viable seeds was higher in small than in large panicles, and was highest in the lowest whorl of the panicle. Dormancy, as percentage of viable seeds, was always lower in first than in second seeds of the spikelets, and reached a maximum of 80 per cent for first seeds 25 days after anthesis, when almost all second seeds were dormant. First seeds taken at a later harvest when fully mature had less dormancy, but this may have been partly the result of a short period of storage in the laboratory before testing. Large panicles had a smaller proportion of dormant seeds than small ones, but dormancy did not vary with position in the panicle.

Further work on the temperature relations of germination of seeds of *A. ludoviciana* which had lost their primary dormancy during 7 years' storage, showed that exposure to 23° or 25° C. did not induce dormancy in first seeds, but as before (*Rep. Rothamst. exp. Sta. for* **1956**, p. 81) very few germinated at 27°, though they did so when transferred to 7°. Dormancy was induced at lower temperatures in second seeds; 25 per cent became dormant at 25° and 4 per cent at 23°. More second seeds germinated when held continuously at 7° after they were imbibed than at 23° or 25°, and germination at 23° or 25° was increased by previous exposure to 7° C. for 1 day or 1 week, though not up to that of seed held continuously at 7°.

In a badly infested field near Bishop's Stortford stubble-burning was observed to have stimulated germination of wild oats seeds (mainly *A. fatua*); counts showed that there were about ten times as many seedlings per unit area where the stubble was burnt as on a few small unburnt patches. However, when ungerminated seeds were recovered by washing from soil samples it was found that for every seed germinated on the burnt patches, about ten remained dormant and presumably viable in the soil. Thus, the stubble-burning was not an effective method of controlling wild oats, because it eradicated only a small fraction of the population of seeds.

Effect of competition with Agrostis gigantea *on response of wheat to nitrogenous top-dressings* (K. J. Witts)

In a field experiment on winter wheat at Woburn in 1956 the response in grain yield to a nitrogenous top-dressing in May was much less than to applications in March or April, and this was thought to be due to competition with *Agrostis gigantea*, which had multiplied in three successive wheat crops on the site to become a serious infestation. On thinly sown plots, where the growth of *Agrostis* was most dense, the late top-dressing failed to produce any increase in the yield of wheat. To test whether the effects of competition with *Agrostis* are more severe when the supply of nitrogen is delayed, winter wheat was grown in pots alone or with variable numbers of *Agrostis* plants, and receiving either no top-dressing or an application of ammonium nitrate on one of three occasions between February and May. Even in the absence of *Agrostis* the late top-dressing was less effective on the wheat than the earlier ones, and in the presence of *Agrostis* the responses to top-dressings at all three

times were decreased. The effect of *Agrostis* was, proportionally, a little greater for the late top-dressing than for the earlier ones, but the explanation suggested for the field results was not wholly substantiated. The weight of *Agrostis* was increased by the nitrogen dressings nearly equally for all times of application. A full interpretation of the results depends on nitrogen analyses of the plant material which are not yet completed.

Weeds of Broadbalk (J. M. Thurston)

Soil samples were taken for the third successive year from five plots of Broadbalk field, to compare changes in the weed-seed population on Section 1a, which has reverted to continuous wheat, and on Section 1b, which remains in the fallowing cycle. The total numbers of seedlings of all species that germinated in the glasshouse in the soil samples taken in 1956, compared with those from the 1955 samples, shows that the weed-seed population almost doubled where the fallow was omitted, but was decreased by one-third after one year's fallow.

Geescroft Wilderness (J. M. Thurston)

This area, which has been left undisturbed since arable experiments on the site ceased in 1867, was surveyed to see how the vegetation has changed since it was last described by Brenchley and Adam in 1913–14. The area has reverted to woodland, consisting chiefly of elm, ash and oak. The largest tree is an oak 81 inches in circumference at 4 feet from the ground, growing near the middle of the area that was cultivated until 1867. Of the forty-six species of angiosperms present in 1957, thirty-two had been recorded previously and fourteen, including eight woodland species, had come in since 1913. In the same period fifty-five species, all characteristic of grassland, had disappeared. All the arable weeds had already gone by 1913.

Weed surveys (J. M. Thurston and K. J. Witts)

The usual records were made of the weed flora of Broadbalk field in May, July and after harvest, and of the flora on the Park Grass plots. The infestation of *Vicia sativa* on plots 3, 5 and 6 of Broadbalk was exceptionally heavy, and on section 4 of plot 5 it nearly suppressed the wheat and caused it to lodge. On this area the vetches produced approximately 300 seeds/sq. ft. and shed them long before harvest. General surveys of the Rothamsted and Woburn farms in May and June showed that the numbers of annual weeds were unusually small, presumably because the spring drought prevented many seeds from germinating. Perennial weeds were less affected by drought, except that *Agropyron repens* at Rothamsted and *Agrostis gigantea* at Woburn received a severe check on sites where spring cultivations had exposed their rhizomes.

Physiological Effects of Virus Infection

Respiration and photosynthesis of infected leaves (P. C. Owen)

When tobacco leaves were infected with potato virus X, the rates of respiration and photosynthesis were unaffected until the

leaves showed symptoms; the respiration rate was then increased by more than 30 per cent and the photosynthesis rate decreased by 20 per cent. The rates of respiration and photosynthesis of leaves of *Nicotiana glutinosa* were unaltered by infection with tobacco mosaic virus (TMV) until local lesions appeared; the respiration rate was then increased by an amount which varied with the number of local lesions, and the rate of photosynthesis was decreased by 20 per cent. With neither of these virus/host combinations was there any effect on photosynthesis or respiration for several days after inoculation. These results differ greatly from those previously reported for tobacco leaves infected with TMV, the respiration and photosynthesis rates of which were affected from within 1 hour of inoculation. Similarly, the water content of tobacco leaves inoculated with TMV and then kept for 20 hours in a saturated atmosphere was less than that of comparable uninfected leaves held in the same conditions, but no such effect on water content during the first day after inoculation was found in tobacco leaves infected with potato virus X or tobacco etch virus, nor with *N. glutinosa* leaves infected with TMV. Thus, in respect of the immediate physiological effects of infection, TMV in tobacco leaves is unique amongst the virus/host combinations yet studied; the validity of extrapolating conclusions based on results obtained from one combination to another is therefore questionable. The results imply that TMV affects tissues below the epidermis earlier in tobacco leaves than in other leaves, and earlier than other viruses in tobacco leaves.

Miscellaneous

Effect of ultra-violet radiation on respiration rate of tobacco leaves (P. C. Owen)

During an investigation of the effect of ultra-violet irradiation on the establishment of virus infection in tobacco leaves, it was found that exposure for 5 minutes to radiation of 2,537 Å. with an intensity of 870 μW/sq. cm. increased the respiration rate of uninfected leaves kept in darkness by 20 per cent. If, after ultra-violet irradiation, the leaves were exposed to sunlight for 2 hours, there was no increase in respiration rate. This phenomenon is similar to the "photo-reactivation" or "photo-reversal" that occurs with other effects of ultra-violet radiation on viruses, fungi and higher plants.

BIOCHEMISTRY DEPARTMENT

N. W. Pirie

Mr. W. E. Whitman has joined the department to apply the methods of food technology to the leaf-protein preparations that are being made. N. W. Pirie attended conferences on "Cellular biology, nucleic acids and viruses" organized by the New York Academy of Sciences and the Poliomyelitis Foundation in January, and on "The origin of life on the earth" organized by the Moscow Academy of Sciences and the International Union of Biochemistry in August. He was the guest of the Czechoslovak Academy of Sciences and the World Federation of Scientific Workers for a week visiting institutes in Czechoslovakia on the way to Moscow. M. V. Tracey returned from leave of absence in Australia on a Royal Society and Nuffield Foundation Commonwealth Bursary. At the invitation of the U.S. Navy he attended a symposium on "Marine biology" in Seattle in September. A. J. Clarke attended the XVI International Congress of Pure and Applied Chemistry in Paris in July.

Plant leaf mitochondria (W. S. Pierpoint)

The enzymes of the tricarboxylic acid cycle and its associated phosphorylations are located on the mitochondria of both animal cells and of non-photosynthetic plant cells, and probably, although there is less evidence for this, on the mitochondria of photosynthetic plant cells. The mitochondria therefore play important roles in cell metabolism, and alterations in their functioning will be reflected in the organism as a whole. Some of the phenomenon of fruit ripening and of plant infections, for example, may be due primarily to mitochondrial disfunction, and a useful understanding of these phenomena requires information on the state of mitochondria in various plant conditions.

Work previously done at Rothamsted has suggested that during the extraction of Rothamsted tobacco necrosis virus from leaves of *Nicotiana tabacum*, the mitochondria produce a virus inhibitor. This inhibitor is responsible in part at least for the variation in infectivity of different virus preparations. In order to characterize further this inhibitor production, and to assess its importance in the intact plant, as well as to provide a basis for the study of healthy and abnormal leaves, work has begun on the preparation from leaves of *N. tabacum* of actively respiring mitochondria.

The most active preparations obtained so far were made by a method which was essentially that which gave active mitochondria from animal and etiolated plant tissues. The leaves were ground in a medium containing 0·4*M*-sucrose, 0·2*M*-tris-buffer, 0·005*M*-ethylenediamine tetracetic acid and 0·02*M*-citrate. The mitochondrial fraction was then separated by centrifugation between 1,000 and 10,000 g. Although omission of any one of the constituents of the extraction medium lowered the oxidative capacity

of the final preparation, citrate was the most essential single constituent.

Such preparations will oxidize, to varying degrees, all the intermediates of the tricarboxylic acid cycle. Highest activity was obtained with succinic acid, and it is with this substrate that optimal conditions for measuring activity of the extracts have been worked out. Addition of the cofactors cytochrome c, diphosphopyridine nucleotide, co-enzyme A and thiamine pyrophosphate stimulates activity, suggesting that the oxidative mechanism is essentially the same as in animal tissues.

The mitochondria in the preparation are probably damaged during their isolation. This is suggested by their requirement for added cytochrome c, and also by their pitiably small oxidation of pyruvate, even in the presence of "sparker" amounts of other acids. The preparations are also impure, for they are bright green in colour and contain a little less than a third of the total chlorophyll in the extracts. Microscopic examination reveals the presence in them of much material resembling disrupted chloroplasts.

Latent phenolase of broad bean (Vicia faba, *L.*) *leaves* (R. H. Kenten)

Water extracts of broad-bean leaves contain much latent phenolase (*Rep. Rothamst. exp. Sta. for* **1954**). It has now been found that active phenolase is released by brief exposure of the extracts to alkaline (pOH 2·5–5·3) as well as acid (pH 3–3·5) conditions. Non-ionic or cationic wetting agents are without effect, but all of the anionic wetting agents tested brought about some activation of the latent phenolase. With the homologous series of sodium *n*-alkyl sulphates the concentration at which activation takes place decreases with increase in chain length. Furthermore, at pH 8 the rate of activation with sodium dodecyl sulphate and sodium dioctylsulphosuccinate is very slow or negligible compared with that at pH 6. Since it is known that the affinity of anions for proteins increases with the size of the anion and that an acid pH favours combination of the anion with protein, the results suggest that the wetting agents activate by virtue of their capacity to combine with proteins. Such combination alters the net charge on the protein, and would permit the dissociation of a phenolase–inhibitor complex held together by salt linkages. Alternatively, configurational changes which sometimes accompany the binding of large anions by proteins could unmask the catalytic centre of a prophenolase. Sufficient evidence is not yet available to decide which of the two alternatives is involved in the activation mechanism.

Enzymes of bracken

This year's and previous work is reviewed in an accompanying article.

Work has continued on the manometric method of following bracken thiaminase action. The general equation for the thiaminase catalysed transfer reaction is

$$P\text{–}CH_2\text{–}T^+ + RNH_2 \longrightarrow P\text{–}CH_2\text{–}NHR + T + H^+ \quad . \quad . \quad (1)$$

where P and T stand for the pyrimidine and thiazole components of thiamine respectively. Since the reactants are bases, and the

reaction gives rise to other bases, which at about neutral pH may differ considerably from the reactants in the extent of their ionization, acid may be released. The amount of acid produced will be a measure of the thiaminase action, and can be estimated manometrically in bicarbonate-CO_2 buffer by following the evolution of CO_2. The following examples of systems at pH 7·5 make this clear. If the acceptor amine is a strong, or moderately strong, base (pKa 10 or greater), then the two extreme possibilities may be written

$$P\text{–}CH_2\text{–}T^+ + RNH_3^+ \longrightarrow P\text{–}CH_2\text{–}NH_2^+R + T + H^+ \quad . \quad (2)$$

$$P\text{–}CH_2\text{–}T^+ + RNH_3^+ \longrightarrow P\text{–}CH_2\text{–}NHR + T + 2H^+ \quad . \quad (3)$$

and between 1 and 2 mol. of acid would be released according to the extent of ionization of the pyrimidylmethyl-amine product. Where the acceptor amine is a very weak base (pKa 5 or less) and the pyrimidylmethyl-amine product is a strong base, then the reaction can be formulated,

$$P\text{–}CH_2\text{–}T^+ + RNH_2 \longrightarrow P\text{–}CH_2\text{–}NH_2^+R + T \quad . \quad . \quad . \quad (4)$$

and no release of acid, and hence no evolution of CO_2, would take place. The manometric method is therefore not suitable for studying such systems.

Using aniline, piperidine, pyridine and trimethylamine as acceptor amines, either on account of their difference in ionization at pH 7·5 or because of the degree of ionization of the product they give by the thiaminase reaction, it was found that there was a reasonable agreement (within 10 per cent) between the calculated and experimental outputs of CO_2, although with thiamine limiting, some 5–10 per cent of the thiamine may be lost in side reactions. The effect of varying such factors as the concentration of thiamine and the concentration and type of acceptor amine have been studied. Conditions have been found under which thiaminase activity can be estimated manometrically. It has been shown that the thiamine analogues heteropyrithiamine and quinilinothiamine, in which pyridine and quinoline replace the thiazole heterocycle of thiamine respectively, and possibly oxythiamine, are thiaminase substrates. Studies of other thiamine analogues have shown, in particular, that 3-(*o*-aminobenzyl)-4-methylthiazolium chloride (ABMT) is an extremely powerful inhibitor of thiaminase action. It is known that ABMT inhibits fish thiaminase competitively, but with bracken thiaminase it was found to act non-competitively; the inhibition was not relieved by increasing the thiamine concentration, and the extent of inhibition increased over the first 30–40 minutes of the reaction period. Concentrations of $2 \times 10^{-6}M$ ABMT inhibited bracken thiaminase by 15–20 per cent, and at $5 \times 10^{-5}M$ ABMT inhibition was virtually complete.

Among the plants, the thiaminase system is restricted to Pteridophytes, and its role *in vivo* is not understood. Evidence about its function could be got if it could be inhibited *in vivo*, but injections of up to 5 mg. ABMT into the stems of bracken fronds caused no obvious damage to develop in a period of 3–4 weeks. The failure

to get an effect may have been due to the ABMT not reaching the site of thiaminase action.

Further purification of plant amine oxidase preparations (A. J. Clarke and P. J. G. Mann)

We have already described a method giving a 300-fold purification of the amine oxidase of pea-seedling extracts. Further improvements have brought the purity of the final preparations to 50 per cent. The enzyme is absorbed on calcium phosphate and eluted by stepwise increases in the concentration of the eluant (phosphate buffer, pH 6·8). To concentrate the purified enzyme in the combined active eluates, the phosphate is removed by dialysis, and the enzyme is reabsorbed on calcium phosphate and eluted with 0·2*M*-phosphate buffer, pH 6·8. Since the purified enzyme is pink, its movement down this column can be seen; at this stage the greater part of the activity in 50 ml. of dilute enzyme has been recovered in less than 1 ml. of eluate. Examined spectrophotometrically, the strongly pink enzyme preparations show an absorption band at 470–550 mμ.

When substrate (putrescine) is added under anaerobic conditions, the pink colour is discharged and the absorption at 470–550 mμ falls. The difference spectrum shows a broad absorption band with a maximum at 490–520 mμ. The fact that this absorption is reduced to less than half by the addition of putrescine is the basis for the suggestion that the purity of the preparation exceeds 50 per cent. Since hydrogen peroxide is one of the products of the reactions catalysed by the enzyme, it is likely that a flavine nucleotide forms part of the prosthetic group. Other workers have obtained indirect evidence of the presence of flavine adenine dinucleotide in the prosthetic group. While the magnitude of the observed absorption is consistent with this suggestion, the position of the absorption maximum is not. Flavine adenine dinucleotide has an absorption maximum at about 450 mμ, and while it is known that combination with proteins may displace its absorption band towards longer wavelengths, the extent of such displacements, so far recorded, are not as great as that required in the present case.

Plant amine oxidase and the formation of heterocyclic compounds (A. J. Clarke and P. J. G. Mann)

We have already reported the formation of norhygrine, a pyrrolidine alkaloid, and of *iso*pelletierine, a piperidine alkaloid, when the amine oxidase-catalysed oxidation of putrescine and cadaverine, respectively, is carried out in presence of acetoacetate. The study of this type of reaction has now been extended, using a range of amine oxidase substrates and four β-keto acids as reactive methylene compounds. CO_2 formation is a measure of those condensation reactions which depend on the presence of the cyclic forms of the products of the amine oxidase reactions. Sometimes the CO_2 outputs approached the theoretical values even at low concentrations of the reactants. Evidence was obtained by paper chromatography that the evolution of CO_2 was accompanied by the formation of a series of saturated heterocyclic compounds whose R_F values differed both with the nature of the substrate and of the reactive

methylene compound. With cadaverine as the substrate and indole as the reactive methylene compound, β-(2-piperidyl)-indole is formed. Reactions of this type are of particular interest, since, in some cases, the products are alkaloids. They are unlikely to occur to any great extent in tissues where rapid specific pathways exist for the metabolism of the unsaturated ring compounds. A likely alternative pathway would be direct reduction leading, with putrescine as substrate, to the formation of pyrrolidine. We have recently obtained a fraction from pea-seedling extracts which catalyses the oxidation of reduced diphosphopyridine nucleotide by Δ'-pyrroline, the unsaturated ring compound formed as a result of of the amine oxidase-catalysed oxidation of putrescine. So far we have been unable to identify pyrrolidine as a product of this reaction.

Peptides as substrates of plant amine oxidase (A. J. Clarke and P. J. G. Mann)

We have already reported that the slow rate of oxidation of the diamino acids, ornithine and lysine, by plant amine oxidase, compared with that of aliphatic diamines of the same hydrocarbon chain length, is due to inhibition by the carboxyl groups of these amino acids. When the carboxyl groups are masked, as in the methyl esters, the rates of oxidation are increased about sevenfold. Lysine amide has now been tested as a substrate for the amine oxidase. It is oxidized at about the same rate as lysine methyl ester. These results suggested the possibility that ornithine and lysine peptides, particularly those in which the amine groups of these acids are not involved in the peptide linkage, might serve as substrates for the enzyme. Lysyl–glycine, however, is oxidized at about the same rate as lysine. In experiments to test whether such oxidation was dependent on the presence of the two free amino groups of the lysine residue, it was found that the methyl ester of glycylglycine was slowly oxidized, and those of di- and tri-glycylglycine more rapidly oxidized by the enzyme. While we have shown that aliphatic monoamines are oxidized by the enzyme, the rate of such oxidation is very slow compared with that of aliphatic diamines. In compounds of this type the presence of two suitably spaced amino groups is necessary for the formation of an active enzyme substrate compound. The fact that the methyl esters of di- and tri-glycylglycine are oxidized much more readily than aliphatic monoamines suggests that an imino group of one of the peptide bonds may take part in the formation of the enzyme substrate compound. These preliminary results therefore suggest the possibility that a new group of substrates of plant amine oxidase may be found among the peptides.

The oxidation of pyridoxine and allied compounds by peroxidase systems (A. J. Clarke and P. J. G. Mann)

Pyridine, α- and β-hydroxy pyridine, pyridyl-β-carbinol and pyridyl-γ-carbinol have been tested as substrates for peroxidase. Only β-hydroxy pyridine was oxidized. This suggests that the oxidation of pyridoxine and allied compounds by peroxidase, pre-

viously reported, depends on the presence of the hydroxyl group in the β position in these compounds.

Blackening of potatoes after boiling (A. J. Clarke and P. J. G. Mann)

Samples of potatoes have been taken from the Rothamsted and Woburn Six-Course Rotation and Dung NPK experiments, to study the effects of the different fertilizer treatments employed on the intensity of the blackening of the potatoes after boiling. In tests made during the first few weeks after harvesting, the differences observed were only small. Further tests will be made after storage. An investigation has also been started of the nature of the pigment responsible for the blackening and of the mechanism of its formation.

The infectivity of fragments of tobacco mosaic virus (N. W. Pirie)

Tobacco mosaic virus retains its infectivity in spite of exposure to treatments that would destroy the activity of most other viruses and enzymes. The infectivity of fragments made from it by disruption with phenol or detergents is, on the other hand, unusually vulnerable. Because the most infective fractions consist predominantly of nucleic acid, various sources of ribonuclease have been tried and found to destroy infectivity with a readiness that approximately parallels their enzyme activity. Saliva is interesting here, for its ribonuclease activity is often overlooked and even when diluted 1 in 1,000 it inactivates TMV fragments. The behaviour of these enzymic inactivators depends greatly on the nature of the buffer in which the tests are carried out, and there is partial protection in the presence of a few known inhibitors of ribonuclease, e.g., heparin, polygalacturonic acid sulphonate and Zn^{++}. In suitable environments these agents also diminish the spontaneous inactivation, but no environment has yet been found in which the infectivity of virus fragments is stable for more than a few hours at room temperature. Other mechanisms of inactivation are probably also playing a part. Thus Ca^{++}, Mg^{++}, glutathione and ascorbic acid are powerful inactivators, as are washings of intact skin and leaves. These effects go some way towards explaining the low infectivity of virus fragments compared to a corresponding amount of the original virus. (With F. C. Bawden.)

Large-scale production of leaf protein (M. Byers, D. Fairclough, N. W. Pirie and W. E. Whitman)

The machinery for making and processing leaf juices has remained essentially unaltered during the year, but it is now all accommodated in a new shed and extension so that the original building can be kept for the clean and small-scale work of handling the finished protein and getting it into the various forms in which it is used. The amount of labour needed to make protein has been greatly diminished by more convenient lay-out and more liberal use of pumps. It would now be possible, if there were demand, to make 100 lb. of protein a week, and more than 500 lb. was in fact made during the summer. Our arrangements for pressing protein into blocks and for wet and dry grinding, canning, solvent extracting, drying and sieving improve steadily.

Young cereals were the main crop used, and this year we included

maize, which comes in conveniently from the beginning of August when there are few other crops suitable for processing. All give unflavoured or pleasantly flavoured products containing 10–12 per cent N before defatting. Bracken was the only other addition to the list of species processed, and from it we could extract 40 per cent of the protein.

We have begun a series of measurements of the yield of protein per acre, and three results are set out in Table 1. The sugar beet

TABLE 1

Some yields of extracted protein from different crops

Date	Crop	Description	Extraction	Lb. protein per acre	% N on DM on protein
22.7.57	Tares	1st cut	1st	99·8	11·77
			2nd	20·3	11·53
19.8.57		2nd cut	1st	26·2	11·44
			2nd	6·6	11·53
31.7.57	Maize	1st cut	1st	50·8	11·28
			2nd	15·8	
29.8.57		1st cut	1st	110·5	11·03
3.9.57	Sugar-beet leaves	High watering	1st	730·0	10·16
		Low watering	1st	477·0	9·66
		Intermediate watering	1st	471·0	9·36

was grown under optimal conditions by the Botany Department, and is included to show the yields at which we aim. At present the two by-products—fibre and low-molecular-weight leaf components—are discarded. The yields quoted are therefore only part, perhaps less than half, of the total product. Furthermore, with crops such as the usual cereals we are off the land and it is ready to take another crop by the beginning of June.

The standard end product is a deep-frozen 5-lb. block containing about 50 per cent of water. Most of this year's production has gone or is going to feed pigs in an experiment at the National Institute for Research in Dairying. Some protein after removal of the lipids with acetone has been used in chicken-feeding experiments at the Rowett Research Institute. Both experiments show that the protein has the high nutritive value that was expected from its amino-acid composition.

Although cooking is no permanent part of the programme of the department, we have been forced to try, both at home and in the laboratory, various recipes so as to have something other than the raw material to show to sceptics. Protein that has simply been washed with water and then canned or kept in deep freeze has so far proved preferable to dried or solvent-extracted material. Cakes and biscuits baked with it are palatable, but the green colour is at first unattractive. In soups, curries, stuffed vegetables or spreads, with some suitable flavours such as herbs, onion, cheese or fish, the colour is more immediately acceptable. If the protein is put into ravioli or a pastry casing with a suitable spice, the colour is less obtrusive; these are probably the most effective vehicles during

the phase in which a green main food seems odd. We have had a great deal of help and advice on cooking, both from members of other departments and from outside Rothamsted, and have had such a steady demand for information and protein, particularly from vegetarians, that we have mimeographed a leaflet of cookery hints. It is clear that in any region or at any time, if there were a shortage of conventional protein, there would be no difficulty in making acceptable and useful foods from this one.

The properties of resistant parts of fungal mycelium which might accumulate in soils (M. V. Tracey)

During the tenure of a Royal Society and Nuffield Foundation Commonwealth Bursary at the Commonwealth Scientific and Industrial Research Organization Wool Textile Research Laboratories in Melbourne, aspects of the solubilization of wool protein by proteolytic enzymes were examined. Conditions under which proteolysis could be activated by the addition of other substances were sought with some success. The effects found, however, were attributable, not to any direct effect on the process of proteolysis as had been hoped, but to reduction of surface denaturation of the enzymes used.

The object of this visit was to learn methods that could be applied to the resistant parts of fungal mycelium in the hope of making them amenable to enzymic attack. This aspect of the work is now being undertaken. Much of the nitrogen in the mycelium is in the form of chitin, so the opportunity was also taken to study the chitinase of termites.

The potato-root eelworm hatching factor (A. J. Clarke)

The Nematology Department has supplied $1\frac{3}{4}$ tons of potato-root diffusate during the past season. Under the conditions mentioned in the previous Report, 90 per cent of the hatching factor is removed from solution by charcoal. In the absence of sufficient water during subsequent elution with acetone, the recovery of the factor is reduced. Contrary to reports by other workers, the charcoal can be re-used after extraction of adsorbed material.

The product obtained by concentrating the acetone solution is an acidic resinous mixture (0·6 g./40 litres root diffusate). Purification by fractional precipitation of the salts formed with various organic bases has not been found satisfactory. A useful initial purification is effected by partition between a buffered aqueous phase and ethyl acetate. By paper and column chromatography, several fluorescent substances present in the starting material are separated. Hatching activity is associated with a discrete spot having a blue fluorescence and phenolic properties. The various properties suggest a coumarin-like structure, and a number of naturally occurring coumarins and related hydroxy-cinnamic acids have been screened for hatching-factor activity. Chlorogenic, caffeic and ferulic acids, as well as aesculin, rutin and 4-hydroxycoumarin have been found inactive.

PLANT PATHOLOGY DEPARTMENT

F. C. Bawden

Staff changes were unusually numerous. Margaret M. Browne, whose work for the department as superintendent of the glasshouses for thirty years has been of inestimable value, retired in September and was succeeded by G. H. King. To the great pleasure of everyone, her meritorious service was acknowledged by the award of the M.B.E. in the New Year's Honours List. J. W. Blencowe and T. W. Tinsley both left to take posts at the West African Cocoa Research Institute and L. J. Cock to join the National Agricultural Advisory Service; A. J. Gibbs, B. D. Harrison and Judith Cox were appointed in their places. L. F. Gates left the Dunholme Field Station, and his successor has yet to be appointed. R. A. Dunning was appointed to a new post of entomologist at Dunholme.

E. W. Buxton was awarded a Kellogg Fellowship and spent three months at the University of California and visiting research stations in the U.S.A. L. Broadbent and B. Kassanis attended the Third International Congress on Potato Virus Diseases in Holland. As the guest of the organizers, F. C. Bawden took part in the International Congress for Poliomyelitis at Geneva, Switzerland, in July, and in symposia on viruses and virus diseases at New York in January and Madison in September. He also attended the meeting of the Advisory Committee for Agricultural Research in the Sudan at Khartoum. J. W. Blencowe and R. Hull attended the meeting of the International Institute of Sugar Beet Research Virus Committee in Holland in January. R. Hull also attended the Summer Congress in Italy in May and L. F. Gates the Winter Congress in Brussels in February.

L. Broadbent was awarded the degree of D.Sc., and R. S. Badami the degree of Ph.D., of London University.

Viruses and Virus Diseases

Work in collaboration with N. W. Pirie confirmed German and American reports that preparations of the nucleic acid from tobacco mosaic could be infective but did not substantiate claims by American workers that infective particles could be synthesized by recombining non-infective nucleic acid with virus protein. Preparations of nucleic acid remain infective for long periods at −15° C., but lose their infectivity rapidly when exposed to many conditions that do not affect intact virus particles, and recombination with the protein may protect against these types of inactivation. Exposure to many biological fluids inactivates the nucleic acid, perhaps because the fluids contain ribonuclease, but this is not a necessary conclusion, because many other substances, both organic and inorganic, are also powerful inactivators. The relative infectivity of nucleic acid

and intact virus depends on the physiological state of inoculated leaves; exudates from leaves resistant to infection by nucleic acid sometimes inactivated nucleic acid more than did exudates from susceptible leaves, but the results were inconstant, and the identity of the inactivators remains undetermined. (Bawden.)

When the phenol method of preparing infective preparations of nucleic acid from tobacco mosaic virus was applied to potato virus X, it gave infective solutions in which no usual virus particles were detected by electron microscopy or serological tests. However, the infectivity was always too slight to be sure that residual virus was not responsible, though this possibility was partly excluded by finding that infectivity was lost in conditions in which normal virus is unaffected. The nucleic acid was also separated electrophoretically from the protein of potato virus X after disruption by exposure to alkali, but this was not infective. This virus does not move in an electric field at pH 7, but both the protein and the nucleic acid do after the particles are disrupted by alkali. (Bawden and Kleczkowski.)

The protein produced by alkali from tobacco mosaic virus moves more slowly than intact virus particles at pH 7; when it is recombined with the nucleic acid its mobility is increased but not restored to that of the original virus. Japanese workers claimed that exposing tobacco mosaic virus for a few minutes at 60° to a potential gradient of 160 V/cm. completely destroys its infectivity and precipitability by its antiserum. This was not confirmed, though both properties were somewhat affected by the treatment.

Experiments on the electrophoresis of antigen–antibody compounds suggested that there was only one kind of bonding between tobacco mosaic virus and its antibody but two between serum albumin and its antibody. (Kleczkowski.)

Electron microscopy

The new Siemens electron microscope installed during the year proved both reliable and satisfactory to use, and the amount of routine examination of virus preparations greatly increased. Using specially prepared test specimens, this machine can give resolutions of the order of 1 mμ, but no such results are obtainable with viruses. Much time has been spent trying to identify and eliminate the limiting factors, but the techniques of making specimens still prevent the microscope from revealing all the details of structure that are theoretically possible. The granular structure of the metal films in shadow-cast preparations of viruses is one limitation, but it is difficult to distinguish this from other sources of granularity, derived from the supporting film, the surface from which it was cast and minute contaminants derived from distilled water, glassware and the air. The presence of oil droplets in the evaporating plant, the rate at which metal is evaporated and the thickness of the final metal film all combine to limit the effective resolution in shadowed pictures of virus particles to about 3 mμ. The greater contrast given by the new microscope when unshadowed mounts of purified viruses are used show that these also are granular, with a grain size similar to that in shadowed mounts, so that improvements in the

methods of shadowing seem unlikely to give much more information on the detailed surface structure of the virus particles.

Electron "stains" seemed to offer some prospect of using the full resolving power to gain information on structure, but unfortunately the small particles of most of the plant viruses are so closely packed internally that too few heavy atoms become attached to give more than a slight increase in contrast. Of the many "stains" tested, only iodine and uranyl acetate stained tobacco mosaic virus appreciably, and neither did so enough to resolve any internal structure. The salt-outlining technique described by Mercer had the serious disadvantage that it gave sufficient contrast only when the contrast medium was present in amounts that prevented high resolutions. Intact rods of tobacco mosaic virus did not stain in the way Mercer described.

There is no problem in determining the gross size and shape of virus particles, but it seems at the moment that most information about their detailed structure is likely to be gained by studying fragmented particles and using their own power to scatter electrons, rather than adding high-contrast material that introduces its own artefacts.

Thin-section work was resumed to study the effects of infection on the leaf components and to try to find the sites of virus multiplication, and was extended to work on the infection of root hairs by *Rhizobium* sp. The structure of montmorillonite was further studied by electron microscopy, and a start was made to explore the value of electron diffraction for this kind of subject. (Nixon.)

Virus multiplication and inactivation

Attempts were made to free chrysanthemum plants from infection by seven different viruses, by growing them for 4 weeks at 36°, after which cuttings were taken from the treated plants. Many of the cuttings were free from tomato aspermy, stunt and ring pattern viruses, but the method did not get rid of vein mottle, viruses B or D, or an unnamed one. Treatment at 36° also failed to free narcissus bulbs from stripe or Wedgewood iris from a virus causing a mosaic disease. (Kassanis and Broadbent.)

Previous work suggested that the ability of thiouracil to prevent the multiplication of viruses was determined more by the identity of the infected host than by the identity of the virus, for all viruses tested in tobacco were affected, whereas none was in beans. However, tests with cucumber mosaic virus suggest that inhibitors of multiplication may act more against some viruses than against others. The multiplication of cucumber mosaic virus in tobacco was only slightly decreased by thiouracil, which almost prevents the multiplication of tobacco mosaic and several other viruses, whereas it was almost wholly prevented by 8-azaguanine, which has only a slight effect on the multiplication of tobacco mosaic virus. (Badami.)

In growing plants such inhibitors prevent virus multiplication but have not yet been found able to free systemically infected plants from infection. Thiouracil, however, freed tobacco callus growing in tissue cultures from infection by potato virus Y. When kept for 6 weeks in media containing 100 mg./litre of thiouracil, the tissues

grew poorly, but they grew normally when again transferred to normal media, and some of such treated cultures have remained apparently free from virus for many months and after many sub-cultures. The amount of virus Y in systemically infected plants was decreased by spraying with thiouracil, but the virus was not eliminated. (Kassanis.)

The knowledge that various treatments decrease virus content suggests that they might be combined to produce virus-free clones from infected varieties that are not cured by one treatment alone. Excising apical meristems from infected plants first grown at high temperatures or treated with thiouracil now obviously warrants testing. Gibberellic acid, too, although it does not much affect virus content, might be of help, as it causes stems to elongate rapidly. Spraying tobacco plants infected with tobacco etch virus with gibberellic acid partially overcame the stunting usual to this infection. Infected plants normally stay in the rosette stage for long periods, but when treated with gibberellic acid their stems almost immediately began to elongate; after two months, however, the growth rate of sprayed infected plants decreased to that of unsprayed ones. The acid makes the leaves more fragile and lighter green than usual, but the seeming similarity of the effect to growing in shade was not accompanied by any increase in susceptibility to infection by tobacco mosaic virus.

Previous experiments showed that the damaging effects of ultra-violet light on plants and viruses could be counteracted by exposure to visible light. The photo-reactivation of viruses, of damage to the epidermis of beans leaves and of the susceptibility of leaves to infection by virus were all produced by visible light of the same wavelengths, and only by wavelengths shorter than 4,700 Å. (Chessin.)

Potato viruses

The aphid infestations of potatoes in 1957, as of most other crops, were greater than in any year since 1940, when we first started observing them. At Rothamsted *Myzus persicae* was even more numerous in May and June than at other places where traps were operated. Other species were also plentiful, and during 10 days at the end of May 5,205 aphids were caught on a trap at Harlow, more than twice as many as were ever caught in previous years during a period of the same length. Potatoes were also infested unusually early, and there were winged and wingless aphids on the Rothamsted crops before most of the plants had emerged above ground. Parasites and predators multiplied rapidly and caused the aphid population to decline; the table shows the course of the infestation of an unsprayed potato crop at Rothamsted and that there was no summer migration of winged aphids from the crop. As a result of the early and heavy infestation there were more plants with symptoms of primary leaf roll and of infection with potato virus Y than have been seen at Rothamsted previously. Whether the beneficial effects of spraying with insecticides in decreasing the spread of virus diseases, found in earlier years, will be obtained in 1957 will not be known until next year, but it seems improbable. Aphids were on the plants before the first spray was

applied, and as DDT did not kill those under the leaves of very small plants, " Metasystox " was also used on the first and second occasions plants were sprayed in the insecticides trial.

Numbers of aphids per 100 potato leaves

Date	*Myzus persicae* Winged	*Myzus persicae* Wingless	Other species
31 May *	90	288	108
12 June	69	371	102
19 June	14	531	243
26 June	35	213	566
3 July	0	30	125
8 July	0	18	54
22 July	0	0	48
20 August	0	4	15
5 September	0	3	158

* On 31 May only one-third of the plants had emerged above ground.

In 1956 DDT emulsion controlled aphids excellently and satisfactorily decreased the spread of virus diseases. Bulk samples of " seed " saved from an experiment in which Stock Seed Majestic was contaminated by 0·8 per cent plants with leaf roll and 0·8 per cent with potato virus Y, gave 6 per cent plants with leaf roll and 4 per cent with virus Y when unsprayed, compared with 1 per cent and 1·5 per cent when sprayed four or six times, with either low- or high-volume applications. Samples of " seed " saved from plants adjacent to the contaminators, gave 24 per cent plants with leaf roll and 18 per cent with virus Y, compared with 0·4 and 3 per cent in sprayed plots. Spraying again increased the yield of tubers; the increase of 6 per cent, 16 cwt./acre, more than balanced the loss of 12 cwt./acre caused by the passage of the tractor through the crop when spraying.

Experiments with insecticides at other places in 1956 gave equally satisfactory results. At Lymington spraying the variety Ulster Prince fortnightly with DDT almost prevented spread, whereas in unsprayed plots the incidence of leaf roll increased nine times and of virus Y by three times. A stock of this variety now in its fourth year at Lymington has only 1 per cent plants with leaf roll and 0·3 per cent with virus Y, whereas at the indicated rate of spread in unsprayed crops the whole stock would now be infected but for the spraying with DDT.

Tests in which seed tubers were planted on top of a small quantity of the systemic insecticide " Thimet " adsorbed on charcoal showed that the treatment prevented aphids from breeding on the plants for at least 4 weeks after they emerged above ground, though it did not prevent winged ones from alighting on them. (Broadbent and Heathcote.)

We have previously reported producing a clone of King Edward VII potatoes free from paracrinkle virus. This year there were enough glasshouse-grown tubers to grow twenty-five in the open, and their performance was compared with that of twenty-five similarly grown but infected tubers. Although there was no obvious difference between the growth or appearance of the two lots of plants, the virus-free clone yielded better than the other. (Kassanis.)

The interactions between potato viruses C and Y were further studied. As obtained from Edgecote Purple potatoes, virus C is not transmissible by *Myzus persicae* and gives only necrotic local lesions when inoculated to the variety Majestic. Our type strain of virus Y is readily transmitted by *M. persicae*, and gives no local lesions in Majestic but a rapidly developing systemic disease, with mosaic and necrotic lesions. From tobacco plants infected simultaneously with both viruses, virus C is often transmitted by *M. persicae*, but transmissions to Majestic potatoes also show that these mixed infections yield a range of variants that differ from both C and Y. Isolates derived from single local lesions in Majestic differ in their ability to invade Majestic systemically and in the severity and type of lesions they cause in uninoculated leaves. Some affect the stems, and may kill parts or all of the plant; others affect only a few of the older leaves. Some are unstable and when continued in tobacco change to forms more nearly resembling the type strain of virus Y. The ability of different isolates to be transmitted by *M. persicae* differs and is decreased by passage through Majestic potatoes. Some, although coming from tobacco plants infected by aphids, could not be transmitted by aphids after being returned to tobacco from local lesions in Majestic. (Watson.)

What seems an unusual strain of potato virus Y was also obtained from a plant of *Solanum jasminoides* sent from India, where the presence of this virus was suspected. From its behaviour in Majestic and other potato varieties, the strain closely resembled our stock of potato virus C, but unlike this one it was readily transmitted by *Myzus persicae*. At least it was so when it was separated from two other viruses present in the *S. jasminoides*, for these decreased the multiplication of the strain of virus Y and its transmissibility by aphids. The other two seem not to have been previously described, and are not serologically related to virus Y or to one another, though all three have long flexible particles of similar size and shape. One was transmitted by *M. persicae*, though only rarely, and no vector was found for the other. (Badami and Kassanis.)

Viruses of cereals and grasses

Symptoms suggestive of infection with cereal yellow dwarf virus were widespread in cereal crops, but the virus could not be recovered from many plants sent here for diagnosis. It was unusually prevalent at Rothamsted, but there is also the possibility that there was some other cause of yellowing. Another small trial to measure the effects on yield of infection introduced at different times gave results different from 1956 and difficult to interpret with certainty. The yield of two wheat and two barley varieties was barely affected, and only oats behaved as in 1956 and gave losses of 17–37 per cent. The apparent lack of effect on yield of wheat and barley could partly be explained by the plants in the control plots becoming naturally infected at the time the second lot of plants were infected artificially. However, unless the strain spreading naturally was more virulent than the one introduced, this seems unlikely to be the whole explanation, for not all the plants in the control plots showed symptoms. Isolates that were more virulent than the one used in the field trial were obtained from naturally

infected plants in different localities, but none was so virulent as some that have been described in the U.S.A. Also, not all isolates seem to have the same host range, and we have failed to infect Cock's foot, which is a host of American strains. Our isolates infected perennial ryegrass, Timothy, crested dog's tail, black twitch, meadow foxtail and *Poa annua*; false oat (*Avena elatior*) became yellow, but attempts to recover the virus from it failed.

All the isolates were transmitted by the aphids *Rhopalosiphum padi, Sitobium fragariae, S. granarium* and *Myzus circumflexus*. In comparable conditions, *S. fragariae* infected only about one-third as many plants as did the other species.

In tests with *R. padi* the proportion of test plants that became infected increased with increasing time the aphids spent on both infected plants and test plants. No infections occurred when the total time on the two was less than 10 hours, and few in less than 24 hours when the infection-feeding time was only 2 hours. With infection-feeding times of more than 8 hours, infections were sometimes obtained in test feedings of 2 hours, so that the period of inability to transmit was shortened by lengthening the infection-feeding time. (Watson and Mulligan.)

Wheat striate mosaic virus was transmitted by all forms and stages of *Delphacodes pellucida*. The insects needed to feed for periods of 9–24 hours to become potentially infective, and the longer the infection feeding was prolonged, the more likely it was that the insects became able to transmit. After leaving infected plants, there was a period of from 7 to 30 days during which they were unable to transmit; once they passed this period, most infected in test feedings of 24 hours and about one in fifty did so in only 20 minutes' feeding on healthy plants. Insects remained infective for weeks or months, and as the virus is egg-transmitted, many progeny of infective females became infective without having themselves fed on infected plants. Some of the progeny of infective females failed to infect wheat plants on which they fed, although it seems they contained virus, for progeny from them were infective.

Wheat striate mosaic virus infected all varieties of wheat, oats and barley that were tested; also rye and ryegrass, but not maize or rice. It was not common enough in cereal crops to be economically important, but it seems to be widely distributed and merits watching. Different strains of *D. pellucida* differed considerably in their ability to transmit, and the occurrence of efficient vectors in large numbers might increase the prevalence of the virus in crops. At the moment it is mainly of interest because of its unusual behaviour in its insect vector; it seems primarily a virus inhabiting the insect and weeds and which only occasionally gets into cereal crops. (Watson and Slykhuis.)

The transmission of ryegrass mosaic virus by eriophyid mites, suspected last year, was confirmed, and the vector identified by Dr. H. H. Keifer as *Abacarus hystrix* (Nalepa). The results of early experiments were inconclusive because the symptoms were slight and transient, but with the use of a more virulent strain of the virus diagnosis became more certain. Of forty-five types of ryegrass inoculated mechanically, more than twenty showed symptoms, which were more evident in Italian than in perennial types. Three weeks after

being inoculated in the three-leaf stage the strain S22 IRG had only two-thirds the dry weight of comparable uninfected plants. The virus also infected *Festuca pratensis*, *Cynosurus cristatus* and *Poa annua*, which promises to be a useful test plant, as it showed a bright mosaic and yellowing of the leaf tips. The virus sedimented when ultracentrifuged for 90 minutes at 20,000 r.p.m., and such sedimented material contained rod-shaped particles about 20 mμ wide and 400 mμ long. (Mulligan.)

The properties of the seed-transmitted barley false stripe virus, reported last year to have been encountered in the French variety Gloire du-Velay growing in Cambridge, were studied. It has stiff particles, about 30 mμ wide and 150 mμ long. Preparations can be fractionated by precipitation with ammonium sulphate (40 per cent saturation) and alternate low- and high-speed centrifugation; like potato virus X, the virus tends to go insoluble, but this tendency can be checked by dissolving the sediments in pH 7·5 citrate buffer. Although sap is not highly infective, it contains much specific nucleoprotein, and an antiserum was readily prepared against it. The virus is inactivated by freezing sap at −15°, but not if sodium chloride or sucrose are added. Barley false stripe virus infected summer spinach, causing a bright mottle and ring pattern. (Kassanis and Slykhuis.)

Virus diseases of sugar beet

Sugar beet yellows was more serious than for several years, an unexpected happening, because the disease was less prevalent at the end of 1956 than in any year since 1942. The unprecedently rapid spread of the disease early in 1957 is attributable to the mild winter, which led to an unusually early and heavy infestation of the crop by *M. persicae*. At the end of May there was an average of twenty-seven *M. persicae* per twenty plants in 150 sampled root crops, compared with the highest previous figure of 1·5. Many of the aphids that came early into sugar-beet root crops in south Cambridgeshire, Essex, Suffolk and the south-east of England must already have been infective, for despite spraying with insecticides in May, all the plants were showing yellows by mid-June. In other fields the same insecticidal treatment decreased the incidence of yellows. This early invasion of the root crop by many infective aphids suggests there may be some previously unsuspected overwintering source of the virus, but the virus may have come from known sources, such as wild beet, clamped mangolds and weed hosts, which may have survived through the mild winter in unusually large numbers. (Hull.)

Wild beet, which continued to increase in many parts of East Anglia, was certainly locally important. In some places the plant grows so vigorously as to present the same general appearance as a densely grown seed crop of beet or mangolds. In the spring *M. persicae* was found breeding freely on wild beet, and aphids were found on about half of the plants examined. There can be little doubt that the insects had over-wintered on them and that they provided one source of virus for the early outbreak of yellows in the beet crops of south-east England.

During the late spring an effort was made to eradicate wild beet

from parts of the beach on the Shotley Peninsula of Suffolk. The plants were sprayed to run-off with an MCPA-type weed-killer, at the concentrations recommended for weed-control in cereal crops. Knapsack and barrow-mounted spraying machines were used, and most of the wild beet was found to be moribund within a few weeks. However, many beet seedlings grew around the dead plants, and it is obvious that spraying would need to be continued for several years to eliminate all plants coming from seed lying dormant on the beaches. Only then would it be possible to observe the rate at which beaches became re-infested by beet seed floating ashore from other parts of the estuaries or coast-line. This test showed that farmers could control the wild beet growing on their own foreshores but an attempt to eradicate the plant from large stretches of beach, would meet many technical and administrative difficulties. (Blencowe.)

Because of the early aphid infestation, crops were examined daily by the staff of the British Sugar Corporation, and warnings were issued of the need to spray when numbers reached an average of one per plant. In consequence, 100,000 acres were sprayed, mostly with beneficial effects, but growers who delayed until the infestation was heavier did not derive the full benefit. Spraying with "Metasystox" decreased the incidence of yellows in all eighteen experiments done in conjunction with the Sugar Corporation and increased yield in twelve. In the south-east, where aphids arrived early, spraying in May increased yield, but in mid-June was ineffective. Further north, a spray in mid-June gave some increase in yield over that obtained by an earlier spray. In crops with less than 20 per cent of the plants affected by the end of August, spraying did not increase yield. Where the incidence in unsprayed crops exceeded 90 per cent, two sprays increased yields by amounts up to 4·5 tons of roots/acre, increased sugar content by 1 per cent and also improved the purity of the juice. " Metasystox " was almost as effective when applied at low as at high volume; other proprietary organo-phosphorus insecticides were less effective, and a proprietary formulation of benzene hexachloride, which was used on some commercial crops, was ineffective.

In previous years when yellows has caused serious losses the disease was worst in regions, mainly the Fens, where seed crops are grown. This year, however, these regions were less affected than the south-east, no doubt because the seed crops started the year healthy because of the certification schemes now operated to provide virus-free stecklings. Only a few stecklings were infected in the autumn of 1956, and counts in June showed only an average of 3·9 per cent plants with yellows in beet seed crops and 6·8 per cent in mangold seed crops. Later, however, the disease increased rapidly because of infective aphids coming into the crops, and some became 100 per cent infected.

In the autumn of 1957, 133 sugar-beet steckling beds had 0·50 per cent of plants with yellows. Five beds were rejected because they had over 1·5 per cent. Four hundred and twelve mangold steckling beds had an average of 4·1 per cent of infected plants; 192 beds had less than 2 per cent infected plants, 174 had between 2 and 10 per cent, and 46 had over 10 per cent. This is the highest

incidence of yellows in stecklings since the certification scheme was started in 1951.

In the autumn of 1957 few stecklings had yellows in a crop raised under barley for the second of the series of experiments to compare a transplanted crop with that grown-on where sown. In June the grown-on plots looked as though they would yield better than the transplanted ones and thus confirm the previous year's results that the grown-on plots gave 11½ per cent more seed than the transplanted ones. Spring applications of TCA at 10 lb./acre and IPC at 6 lb./acre decreased weeds and volunteer barley without visibly injuring the beet plants. In contrast to 1956, autumn treatments were not as effective as spring treatments. (Dunham, Gates and Hull.)

Seed treatment, and applying "Thimet" and Disyston to soil at sowing, gave beet seedlings which were toxic for up to 6 weeks to aphids in Petri dishes. The treatments did not control yellows in the root crop at Dunholme, where most spread of yellows occurred after the toxic effects had worn off. Stecklings from seed sown in August with similar treatments were also toxic to aphids; the effects on yellows incidence will not be known until next June. (Gates.)

Seed of inbred lines of sugar beet selected over 10 years for resistance to yellows was distributed in the spring to commercial breeders and to the Plant Breeding Institute. In a trial near Ipswich, where yellows was severe, line A7S/1 outyielded Sharpes E and Battles E in sugar per acre by 13 and 27 per cent respectively, and line Q1S/1 outyielded them by 16 and 30 per cent respectively. Some lines showed symptoms of yellows later than others; for instance, in early July line 55/21/6 had 14 per cent of plants with yellows, whereas Sharpes E had 73 per cent. Production of seed and testing of other selections was continued. (Hull.)

Myzus persicae multiplied more rapidly on plants with yellows than on healthy plants in the glasshouse, and more rapidly on plants infected with an avirulent than with a virulent strain. (Baker.)

The virus isolated previously from wild beet, and called water mottle, appears to be related to beet mosaic virus. It does not protect plants against infection with the mosaic virus, and the two viruses can multiply in the same plant, but the necrotic local lesions characteristic of infection with water mottle do not develop when the virus is inoculated to leaves with symptoms of beet mosaic. The type of symptom caused varies widely with the genetical constitution of the beet. Five inbred lines from Dunholme were compared with Kleinwanzleben E for the amount of stem necrosis produced. Two lines developed none, and their symptoms resembled those of beet mosaic. One was nearly defoliated by stem necrosis, one had about the same amount of necrosis as Klein E and the fifth had about half as much stem necrosis. The necrosis increased as light intensity and day-length decreased. The virus was transmitted by both *M. persicae* and *M. ascalonicus*, but much less readily than beet mosaic virus. All beet mosaic viruses obtained from wild beet contained the water-mottle virus, but one from Barnfield 1957 did not. (Watson.)

Gamma-rays prevented sprouting of stored mangolds (*Beta vulgaris*) in a trial carried out in the winter of 1956–57. Orange

Globe Mangolds, in batches of five, were irradiated at Harwell on 7 November 1956. After treatment the mangolds were bedded in damp sand in an unheated building at Dunholme. On 8 April 1957 the mean lengths of the sprouts were 5·7, 3·2, 1·5, 0·0, 0·0 and 0·0 inches on the batches given 0, 5,000, 10,000, 20,000, 30,000 and 40,000 rads respectively.

Apterous viviparous *M. persicae* were irradiated at Wantage with gamma-rays and returned to Dunholme, where they were cultured for about 10 days on young turnip plants in the glasshouse. Doses of 14,000 and 12,000 rads arrested reproduction; doses of 10,000, 8,000 and 6,000 reduced it, and a dose of 4,000 rads had no perceptible effect on it.

Tetrachloronitrobenzene was more effective as a sprout depressant on topped than on untopped mangolds, when, after treatment, they were bedded in damp sand in an untreated building during the winter. The tetrachloronitrobenzene inhibited the sprouting of a mangold but only when actually touching it, and ceased to act in this way as soon as the powder was washed off. (Cornford.)

Mycology

Potato diseases

The early phases of potato-blight epidemics were studied for the fourth successive year: 580 naturally and 590 artificially infected tubers were planted among 1,500 healthy guard tubers. For the first time in the open *Phytophthora infestans* invaded stems from naturally infected tubers (two), and again it did so from two artificially infected tubers. Part of the plot was irrigated to make the mean weekly precipitation equal to 1 inch, about twice average rainfall. The purpose was to test whether this increased or accelerated the invasion of stems by the fungus, but there was no evidence that it did. However, there were several pockets of infected plants in the irrigated plot that could not be associated with fungus coming from invaded stems, a phenomenon not found before.

The first invaded stems were found on 16 July 1957, considerably later than in 1954 (28 May) or 1956 (12 June). In 1955 no invaded stems were found. The late appearance in 1957 may have resulted from the hot sunny weather during most of June, which gave soil-surface temperatures over 100° F. July was cool and wet, and the disease spread from the initial sources more rapidly than previously recorded. Only 4 weeks elapsed between the outbreak starting and all plants in the plot being infected, compared with 8 weeks in 1954 and 7 in 1956. The rapid spread compensated for the late appearance of the fungus above ground, and as usual blight outbreaks were common in the district during the first half of August. The disease then developed slowly until mid-September, when both sprayed and unsprayed plots were rapidly destroyed. Increase of yield (0·72 tons/acre) from two protective copper oxychloride sprays was not statistically significant; nor was tuber infection (1 per cent) important on the variety Majestic at lifting.

Last year we reported a first estimate of the proportion of infections on plants within a crop that results from spores transferred by leaf contact or dripping water. Repetition of the experiment in

1957 again suggested that about half (43 per cent) of the infections originated in this way.

Records from a surface-wetness recorder exposed beneath an undisturbed potato canopy were compared with those of a similar instrument exposed at the level of the canopy. Leaves below the canopy remained wet considerably longer after rain, but the reverse applied on dew nights when lower leaves often remained dry. (Hirst and Stedman.)

In 1956 the rates at which the varieties Up-to-Date, King Edward, Majestic and Arran Viking were attacked by blight in small plots, planted as a 4 × 4 Latin Square in a crop of Majestic, were unexpectedly similar. To test whether differences in field resistance were obscured by this arrangement, two differently placed 4 × 4 Latin Squares were used in 1957; in one the plots were surrounded by guard rows of the same variety as in the plot, which allowed interactions between varieties to be studied in the guards, and in the other the varieties were surrounded by an equal area of kale.

The tall dense canopy of Up-to-Date affected the microclimate in adjacent rows of other varieties, but there was no obvious spread of blight from plots of one variety to those of another. The rate at which different varieties were destroyed by blight differed no more than in 1956, but the two experiments gave different results. In the experiment with plots surrounded by potato plants all the varieties were 50 per cent defoliated within 3 days of each other, with Arran Viking rated to be as susceptible as Up-to-Date. In the other experiment there was a difference of 6 days, and Arran Viking became 50 per cent defoliated 3 days later than Up-to-Date. King Edward was the first variety to be 50 per cent defoliated in the experiment with guard rows of potatoes and the last in the one with guard rows of kale.

Blight appeared in both experiments in early August, but developed more slowly in the plots surrounded by kale, which reached 50 per cent defoliation 7–10 days later. Unfortunately this experiment was planted 14 days later, so that the two crops were not comparable when blight appeared. Whether differences in microclimate or supply of inoculum determined the rate at which blight developed is difficult to assess.

Other studies suggested differences between the varieties that might determine the rates at which they are destroyed. Inoculating the leaf axils of plants in the glasshouse with drops of a spore suspension showed varietal differences in the susceptibility of petiole and stem. Thirty such inoculations to Up-to-Date, King Edward, Majestic and Arran Viking produced 13, 8, 1 and 0 stem lesions and 19, 20, 2 and 1 petiole infections respectively. In the field in 1957 stem lesions were very frequent in Up-to-Date and King Edward, few in Majestic and even rarer in Arran Viking. Observations of marked leaflets in the field showed that petiole infection killed 30, 25, 16 and 6 per cent of leaflets in the four varieties. Lesions on leaflets occurred most often at the tips and edges, places where water persisted. No difference was noted in the time between infection and lesion formation or spore production on the four varieties, but as in 1956 the extent of sporulation differed in different varieties.

Resistance of tubers to infection increased in the order Up-to-Date, King Edward, Majestic and Arran Viking.

The common race of the fungus was Race 4, but plots of the hypersensitive varieties Orion (R_1 gene) and Pentland Ace (R_3) became infected at the beginning of September, and the races responsible were identified as 1, 4 and 3, 4 respectively.

A report that a spray containing potassium silicate controlled blight on outdoor tomatoes led to small-scale tests in the laboratory and glasshouse. Commercial potassium silicate (66° TW) incorporated in a chick-pea agar at 0·5, 1·0 and 5·0 per cent concentrations prevented the growth of the fungus, and in water inhibited the germination of sporangia. When sprayed on tomato plants, 5 per cent silicate was phytotoxic, but this and lower concentrations applied a few days or hours before inoculation with *P. infestans* failed to prevent blight. The effects in agar and water probably result from the pH of 9–10.

The incorporation of a sticker (2 per cent Celacol) and/or a wetter (1 : 8,000 Manoxol) with the spray decreased the mean number of lesions per leaf from 217 (1 per cent silicate) to 18 (silicate plus wetter and sticker), but wetter alone also decreased lesions from 158 to 6 lesions per leaf. Some batches of the commercial silicate were contaminated with traces of soap, which may explain the control claimed. (Lapwood.)

Two fungicides, thiram and PCNB, which decreased the incidence of the browning caused by *Oospora pustulans* on potato roots and stolons in 1956, were used again in 1957 at Rothamsted and Woburn. A 10 per cent thiram dust applied to the seed and the furrow at 150 lb./acre decreased the disease rating (DR) from 54 to 41 per cent at Rothamsted, and from 48 to 21 per cent at Woburn. Applied only to the furrow, it had no effect, and applied only to the seed, it decreased the DR at Woburn (21 per cent) but not at Rothamsted (53 per cent). Similarly, a 20 per cent PCNB dust applied to the seed and to the furrow at 300 lb./acre decreased the DR at Rothamsted (19 per cent) and at Woburn (34 per cent), and also at Woburn (19 per cent) when applied only to the seed. Dung at 15 tons/acre had no effect on the disease. Seed and furrow treatment with thiram and PCNB also decreased eye infections and the incidence of skin-spot lesions when the tubers were stored. In the clamp skin spot developed on 74 per cent of tubers from untreated plots and on only 28 and 39 per cent from plots and seed treated respectively with thiram and PCNB.

Majestic seed tubers free from *O. pustulans* were used in a small field trial to test the effect of inoculation at planting time. Tubers dipped in a mycelium and spore suspension all produced shoots with severely browned roots and stolons, whereas most uninoculated plants had no browning. Inoculation decreased the number of tubers at lifting time by 24 per cent, but their weight by only 9 per cent.

The incidence of lesions on root and stolons was recorded late in July on maincrop varieties at six National Institute of Agricultural Botany centres. As in previous years, it varied considerably with locality and variety. The DR was lowest on black fen soil (18 per cent) and highest on medium loam at Sprowston (48 per cent) and

heavy silt at Terrington (40 per cent). The average DR at all centres was highest on Majestic (57 per cent) and Ulster Torch (50 per cent) and lowest on Ulster Supreme (10 per cent) and Arran Viking (9 per cent); this reflected the extent to which eyes on the original seed tubers were infected. Only the Majestic seed had appreciable skin spot postules; Ulster Torch had none. (Salt.)

Apple scab

Work on apple scab, caused by *Venturia inaequalis*, was continued in attempts to improve the forecasting and prevention of outbreaks. In the Wisbech area of Cambridgeshire spraying of Bramley's Seedling was again done with phenyl mercury compounds applied to act therapeutically soon after weather favouring infection occurred. Since introducing this practice, the disease has become much less prevalent, even though only about half the number of sprays formerly given are now applied. Our observations are necessarily restricted to sprayed orchards, and so we cannot establish how much of the improvement results directly from the new practice, but there is circumstantial evidence that much does. For example, in the 2 years since the accurately timed sprays have been applied in one orchard the ascospores caught have averaged only 4 per cent of the number caught during the three previous years; and in a second orchard a similar decrease occurred between 1956 and 1957 with the introduction of the timed sprayings. Also, whereas dead leaves from other orchards in the district continued to produce many ascospores in the spring, leaves from these two produced few.

The number of ascospores to which trees are exposed in the spring depends on two factors; the amount of dead leaves per unit area of ground and the yield of ascospores per unit area of dead leaves. The accurate timing of curative sprays controls scab so well that infections occur only on leaves formed at the tips of extension growths after spraying is stopped, but in different orchards different quantities of dead leaf survive through the winter. In three sampled in December 1956 the dead leaf (dry matter) amounted to 1,395, 990 and 860 lb./acre, whereas in March 1957 these weights had fallen to 718, 92 and 29. Attempts will be made to find what causes such differences and the importance of surviving leaves in initiating scab outbreaks.

The simplified surface-wetness recorder, used to indicate periods suitable for infection by *V. inaequalis*, was developed further in conjunction with the Meteorological Office, and a prototype, which was tested successfully, has now gone into production. Valuable as it is, however, the instrument does not provide the complete answer for detecting meteorological conditions that allow infection. Further information is needed on how temperature affects the required period for leaves to remain wet, and on the duration of dry periods, within wet spells, that are lethal to the fungus. (Hirst and Stedman.)

Cereal diseases

Stunted plants and whiteheads caused by *Ophiobolus graminis* occur most years on Broadbalk, but 1957 was the first year in which

the attack was so severe that patches of plants were killed. The take-all patches were all on the east half of the field, and their outlines spread over plot boundaries; they all occurred on plots that had been limed, and they were worse on land that had been acid before it was limed. As usual, the disease was negligible in the crop after fallow, but unusually it was worse on plots 8, 13, 14 and 15, which received nitrogenous fertilizers, than on plots which did not. The unprecedently low yield of 7·1 cwt./acre for plot 8 VB was correlated with 85 per cent of the plot showing take-all patches; 8 VA, of which only 12 per cent showed take-all, yielded 19 cwt./acre. (Glynne.)

Preliminary experiments, in which wheat was grown in pots containing soil from different fields, suggested that this method might indicate the amount of *O. graminis* present, for the incidence of take-all in the test wheat was correlated with its incidence in previous crops in fields from which soil was taken.

Earlier experiments showed that the identity of preceding crops greatly affects the incidence of take-all and eyespot (*Cercosporella herpotrichoides*) and the yield of wheat. The land from the discontinued four-course rotation experiment was used to try to assess the relative effects on yield of these two diseases and other factors; for this purpose wheat, spring barley and oats were taken where wheat or barley had been grown in 1955 or 1956. The 1957 wheat crops following wheat or barley in 1956 had an average of 78 per cent straws infected by *C. herpotrichoides*, and 11 per cent of the plants had *O. graminis* on their roots in July. On land where wheat or barley in 1955 was followed by potatoes or beans in 1956 the 1957 wheat had 22 per cent of straws infected with *C. herpotrichoides* and 0·3 per cent with *O. graminis*. The 1957 barley suffered little from either disease, and the oats appeared free from both. All three yielded better on land which carried potatoes or beans in 1956, but whereas oats yielded only 6 per cent less on land that carried wheat or barley in 1956, barley yielded 13 per cent and wheat 29 per cent less.

The survival of *C. herpotrichoides* was estimated by finding the number of pieces of straw on the surface that produced spores when incubated in the laboratory. The average number per square yards was twenty-seven where wheat or barley was taken in 1956 and only one where it was taken in 1955. In February the incidence of eyespot lesions was 46 per cent in wheat growing on the first and 2 per cent on the second plot of land. (Glynne and Cock.)

In the second year of an experiment measuring effects of sowing date, seedrate and nitrogen, Cappelle wheat was grown on rich land free from eyespot and take-all. Mean grain yields (excluding edge rows) were 51·9, 50·8, 49·1, 46·7 cwt./acre for plots sown 18 September, 15 October, 8 November and 4 December respectively. Early sowings yielded less, and later ones more than last year, except that Koga II wheat sown in March yielded only 39 compared with 46 cwt./acre last year. The September to November sowings yielded most at 1½ and the December sowing at 4½ bushels/acre. Last year nitrogen affected yield little, but 6 cwt. sulphate of ammonia gave the highest mean yield. This year added nitrogen depressed yields, especially of the October and November sowings; plots that received

3, 6, 9 cwt./acre sulphate of ammonia respectively gave mean yields of 52·4, 49·6 and 46·8 cwt./acre. Although the crop was apparently supplied with ample nutrients, the outside rows yielded more than the inner ones, and those on the south side yielded more than those on the north; in both years the relative difference between outside and inside rows decreased with lateness of sowing. The winter wheat was attacked by larvae of *Opomyza florum*, which entered and killed tillers in March and April. Early sown wheat was more heavily infested than late; on 2 April wheat sown in September, October, November and December had respectively 83, 32, 7 and 5 per cent plants and 36, 9, 2, 2 per cent shoots infested. The tillers damaged were mostly late formed ones, and the effect on yield did not seem serious. (Glynne and Slope.)

To measure the loss in yield of wheat caused separately by take-all and weeds, a site was selected on Highfield which had grown five successive wheat crops, the last two of which have failed because of severe take-all and weeds. In preparation for the experiment in 1957, the site was cropped in 1956 with Cappelle wheat, and S 172 winter oats, to give contrasting levels of take-all infestation without interfering greatly with the weed population or soil fertility. At harvest 70 per cent of the wheat straws were severely affected by take-all, and 98 per cent had infected roots. The oats were not infected. In 1957 Koga II wheat was drilled over the whole site, but the results were disappointing because in spite of its previous severity, take-all was not sufficiently prevalent to cause appreciable loss. Spraying with CMPP (4-chloro-2-methylphenoxy proprionic acid) controlled chickweed and other weeds which became abundant in unsprayed plots, but it also increased severe take-all from 14 to 26 per cent straws infected after wheat, and from 8 to 16 per cent after oats. The increased grain yield from spraying, 0·7 cwt./acre after wheat and 1·3 cwt./acre after oats, was too small to be significant statistically; the gain from weed control was apparently offset by the increase in take-all. (Salt.)

A new cereal rotation experiment was begun on land previously cropped with beans in 1956 and spring wheat in 1955. The crops to be used, viz., winter and spring wheat, spring barley, spring oats and field beans, can all be machine-drilled and combine-harvested, and the object of the experiment is to grow these crops in a sequence in which neither eyespot nor take-all becomes severe enough to reduce yields. In July this year 1 per cent of the straws of the winter wheat were infected by eyespot, but there was no infection of the spring-sown cereals. The grain yields were: winter wheat 45·5, spring wheat 39·7, barley 40·7, oats 27·3 cwt./acre. (Slope.)

Changing temperature affected different attributes of *C. herpotrichoides* differently. Spores were produced on discs of pure culture more quickly at 10° C. (3 days) than at 5° C. (10 days), and discs at 15°, 20° or 25° C. produced no spores. Discs that had been at 15–25° C. for periods up to 17 days began sporing within a week when transferred to 10° C. Naturally infected straws which were already sporing stopped sporing within 3 days at 25° C., between the 6th and 10th day at 20° C. and between the 12th and 14th day at 15° C. Increasing temperature increased the rate at which spores germinated; 80 per cent germination required 20 hours at 15–25° C., 44

hours at 10° C. and 92 hours at 5° C. Lesions also develop on wheat seedlings quicker at the higher temperatures. Single seedlings growing in test-tubes containing culture solution were inoculated on the coleoptile with one drop of spore suspension and placed in humid chambers, where they developed black stromata on the first leaf sheath within 21 days at 25° C., 14 days at 20° C., 24 days at 10° C., 28 days at 5° C. The only sporing occurred within 14 days on the coleoptiles of plants at 10° C. although there were no visible lesions. (Salt.)

Diseases of peas

The mechanisms of variation in *Fusarium oxysporum* f. *pisi*, the cause of pea wilt, were further studied to see whether changes in pathogenicity were influenced by the host. There is good evidence that exposing bacteria to appropriate substrates induces them to form enzymes that attack the substrates, but little is known of the ability of fungi to adapt when exposed to host-produced substrates. The pea wilt fungi provide an opportunity to study this problem, for exudates from roots of pea varieties that are hosts for different pathogenic races affect the spores of different races differentially. For example, spores of race 1 cannot grow in exudate from the roots of the variety Alaska, which resists it, whereas the growth of race 2, which can wilt Alaska, is stimulated by the exudate. Tests were therefore made of the pathogenicity of race 1 spores after exposing them to root exudate from the variety Alaska. Spores were kept for 14 days in concentrated exudate, or were transferred at periods of 48 hours to a series of increasing concentrations of exudate for 14 days, when they were inoculated to the susceptible pea variety Onward and to the resistant Alaska. After 26 days, 84 per cent wilt was recorded in Alaska inoculated with spores kept in concentrated exudate and 100 per cent with those exposed to higher concentrations. Alaska inoculated with spores kept in sterile water did not wilt. Similar results were obtained whether the spores grew in the exudate (incubation at 25° C.) or were in a resting state (incubated at 4° C.). Not only did the exudate-treated spores infect and wilt Alaska, but their usual 100 per cent ability to wilt the susceptible variety Onward was decreased to a mean of 73 per cent.

This action of Alaska root exudate in conferring pathogenicity towards Alaska, and simultaneously decreasing the virulence of race 1 towards Onward, may occur because of a mechanism similar to enzymatic adaptation, or because mutants of altered pathogenicity were selected by the exudate. The fact that there were no wilted plants in the controls inoculated with spores kept in sterile water, nor any healthy plants among those inoculated with exudate-treated spores, however, makes it unlikely that selection of random mutations was responsible.

The adapted cultures of race 1 maintained their changed pathogenic abilities through six successive isolations from and re-inoculations to Alaska peas. Preliminary tests do not suggest that the changes in pathogenicity are accompanied by ability of the spores to germinate in Alaska root exudate.

Exposure to products of the actinomycete *Streptomyces albido-*

flavus also produced changes in the pea-wilt fungus, which after such exposure grew in solutions that previously inhibited growth.

Solutions of DNBP applied to a wilt-sick field at Rayne, Essex, delayed the onset of wilt, but towards the end of the season the disease was equally severe on treated and untreated plots. Of new pea varieties from New Zealand (supplied by the National Institute of Agricultural Botany, Cambridge), tested at Rayne, Blue Prussian had 28 per cent plants wilted, Greenfeast 35 per cent and Resistant Onward 46 per cent, compared with English Onward 100 per cent; wilt occurred 3 weeks sooner in the English than in the New Zealand varieties. Tests for resistance in glasshouses at Cambridge and at Rothamsted, using three soil types, gave results similar to those obtained in the field. (Buxton.)

When *Fusarium oxysporum* f. *pisi* and *F. solani* f. *pisi* (the cause of wilt and foot rot of peas respectively) are inoculated together to peas, variety Onward, wilt occurs more slowly and is less severe than when *F. oxysporum* is inoculated on its own. This effect occurred with both race 1 and race 2 of *F. oxysporum* f. *pisi*, and it was increased by increasing the amounts of *F. solani* added to a constant amount of *F. oxysporum* in the inoculum. It also occurred in both sterile and non-sterile soil, showing that other soil-borne micro-organisms are not involved in the effect.

F. solani has no antagonistic effect on *F. oxysporum* when the two are grown together on agar media, and culture filtrates of *F. solani* do not affect the growth of *F. oxysporum*. It seemed that the host plant may be affected by *F. solani* so as to affect the entry or development of *F. oxysporum*, but root exudate from a plant infected with *F. solani* did not inhibit the germination of spores of *F. oxysporum* and extracts from foot-rot lesions inhibited only slightly.

The interaction seems of little practical importance in the field, for many plants of the variety Onward growing in a wilt-sick field contained *F. solani* f. *pisi* in the stem before *F. oxysporum* f. *pisi*. Later, when pods were beginning to form, *F. solani* f. *pisi* was found in 50 per cent and *F. oxysporum* f. *pisi* in 90 per cent of the plants examined. The peas died soon after, and at most it seems *F. solani* only delayed the development of the disease. (Perry.)

Clubroot of crucifers

As part of an attempt to find better differential hosts for strains of *Plasmodiophora brassicae*, radish varieties were tested for their susceptibility to several isolates. No useful differential effects were observed, but the varieties differed greatly in their susceptibility to all isolates. For example, almost all plants of the variety Woods Frame, a long radish, showed symptoms, whereas the turnip radish, Red Forcing, was highly resistant. The types of symptom varied from well-developed clubs to small black necrotic lesions, a symptom recorded only for radishes.

As alternatives to mixtures of sand and soil as media for growing clubbed plants, trials were made with mixtures of sand and peat. Cabbage seedlings were transplanted to the mixtures in pots, inoculum was poured on to the surface and nutrients added in solution. With sphagnum peat and sand in equal volumes, growth of the

plants was retarded at first and there was little or no infection, but clubs developed when the peat was diluted with three times its volume of sand. Sedge peat was better and clubs formed consistently and more quickly in mixtures of it with sand in the proportions of 1 : 1 or 1 : 3, and such mixtures may be preferable to many soils for clubroot experiments.

The technique devised by Fahreus of growing clover seedlings in agar between a slide and a cover-glass for observing infection by *Rhizobium* was used successfully with crucifer seedlings and *P. brassicae* by incorporating spores in dilute Hoagland's solution with the agar just before it sets. The method promises to be useful in studying, for example, penetration by the zoospores and for experiments where it is important to keep the inoculum in a fixed position near the root.

Before counts of root-hair infections can be analysed statistically they must be transformed to a logarithmic function to make the standard errors independent of the mean. Several such transformations were tried on many results, and the most generally applicable was that devised by Kleczkowski for virus local-lesion counts.

Several questions relating to the sampling of seedlings with root-hair infections were investigated. There is no evidence of any correlation between the length of the root and the number of infections sustained by it, but in one experiment with seedlings 4·6–5·5 cm. and 5·6–6·5 cm. long the most infections occurred on 2nd, 3rd and 4th cm. of root, measured from the junction with the hypocotyl, with few near the hypocotyl or tip. The distribution of infections was affected by treatments, and although sampling only a part of the root has the advantages of easier handling on the microscope, at present it seems safer to sample along the whole root. (Macfarlane.)

Sugar-beet diseases

The effects of seed treatment with fungicides and insecticides were again determined at seventeen centres in co-operation with the British Sugar Corporation. Fungicides increase the stand of seedlings by about 40 per cent, but insecticides gave little additional increase. Seed steeped in ethyl mercury phosphate solution gave 10 per cent more seedlings than seed treated with dry organomercury dressings. Ten tons of seed steeped in ethyl mercury phosphate proved satisfactory when used commercially, and in the Sugar Corporation's trials with low seeding-rate, precision drills gave 10 per cent better stands of seedlings than dry-dressed seed.

Seed of a polyploid variety of sugar beet, which had shown severe injury by γ-BHC seed dressing in 1956, was treated with various dosages of different γ-BHC formulations. No injury to foliage or roots was observed this year; evidently the injury in 1956 had seasonal causes. (Gates.)

Sprays containing 0·1 and 0·05 per cent streptomycin, applied 1 day before the plants were artificially inoculated, effectively controlled downy mildew (*Peronospora schachtii*) on sugar-beet seedlings in the glasshouse. The sprays were less effective when inoculations were made 5 or 7 days after the seedlings were sprayed, and they had no effect when inoculations were made 11 days after.

Pleospora betae Bjorling, the ascigerous form of *Phoma betae*

Frank, was first found in this country at Dunholme, Lincs, in October 1957. The black hemispherical perithecia, about 300 μ in breadth, were found in abundance on the bark of dried stems of wild beet (*Beta vulgaris*). Cultures obtained by the Commonwealth Mycological Institute from the transversely and vertically septate ascospores were found by them to be identical with cultures obtained from the pycnospores and from a black-leg lesion on a sugar-beet seedling. (Cornford.)

Clamped sugar beet decomposing in January in Essex were invaded by many different fungi and bacteria. It was concluded that they were not primary pathogens but were growing on beets injured by severe frosts in November. (Hull.)

Entomogenous fungi

In collaboration with D. Long (Entomology Department), wheat-bulb flies (*Leptohylemyia coarctata*) showing symptoms that appeared to be correlated with fungal attack were examined. Three major symptoms were distinguished:

(1) Cysts in abdomen, internally covered by sporulating fungi.

(2) Abdomen converted to a white non-sporing mycelial mass.

(3) Abdomen distended and full of spores of a red fungus.

Among many fungi isolated, *Entomophthora grylli*, *E. muscae*, *E. coronata*, *Cephalosporium* sp., *Penicillium* sp. and *Mucor hiemalis* were common and *Fusarium roseum*, *Stemphylium* sp. and several bacteria more rare.

Spore suspensions were prepared from cultures of *E. grylli*, *Mucor hiemalis* and *Cephalosporium* sp. and sprayed on live flies in cages kept in the laboratory, or sprayed on live flies in nylon cages kept outside. Flies were also fed on fungus cultures before they were released into cages outside.

Control flies were sprayed with water or fed on plain agar media. Daily observations of death rates showed that, 10 days after inoculation, a mean of 40 per cent had died in each of the three treated sets, and the fungi used as inoculum were readily isolated from flies bearing the original symptoms. The controls, which remained healthy at first, had an equally high death rate after 10 days, although deaths were mostly from causes unrelated to those in the inoculated sets. (Buxton.)

NEMATOLOGY DEPARTMENT

F. G. W. Jones

R. D. Winslow joined the staff in June and has begun work on migratory soil nematodes. Joan M. W. Hurrell left in February. In July F. G. W. Jones paid a short visit to the U.S.A. and took part in a nematology " seminar-workshop " held at the Agricultural Experiment Station, Knoxville, Tennessee, later visiting three research centres in Alabama and Florida. In September C. C. Doncaster, Mary T. Franklin, J. J. Hesling, F. G. W. Jones and R. D. Winslow attended the 4th International Nematology Symposium in Hamburg. F. G. W. Jones was chairman of the opening session and also of a session in the 4th International Congress of Crop Protection that followed.

As in previous years, many specimens from home and abroad were received for identification. By far the greatest number from abroad were species of root-knot eelworm (*Meloidogyne*). Other nematodes of special interest received were *Sphaeronema* sp. from Indonesia on citrus roots and *Radopholus similis* from Jamaica on banana roots. A sample of galled tomato roots from a glasshouse at Wokingham, Berks, contained a species of *Nacobbus*, the first record of the occurrence of this genus outside the U.S.A. The species of *Sphaeronema* has been described, and further observations are being made on the host range and biology of the species of *Nacobbus*.

Non-Cyst-forming and Other Soil Nematodes

Investigations on migratory soil nematodes have been started, with a view to assessing their prevalence and economic importance. Initial work shows that species of *Tylenchorhynchus*, *Tylenchus*, *Pratylenchus*, *Rotylenchus* and *Paratylenchus* are widespread in permanent grassland and various cultivated crops. All five genera contain known or suspected root-feeding species. Other genera encountered and containing known or suspected plant parasites are *Aphelenchoides* (encountered frequently), *Longidorus* and *Aphelenchus* (occasionally), and *Paraphelenchus* and *Criconemoides* (rarely). Nematodes apparently identical with T. Goodey's *Anguillulina obtusa* (1932 and 1940) have been found in Rothamsted turf. They are believed to represent a new genus close to *Pratylenchus*. (R. D. Winslow.)

Work on the relationships of *Hoplolaimus uniformis* to Sitka spruce seedlings, in conjunction with the Chemistry Department, has finished. An experiment, in which individual seedlings were grown in sterilized Ringwood soil and inoculated with 0, 20 and 200 eelworms per plant, gave striking evidence of the damaging effect of the eelworms. All the work of the last few years has been written up, and will form a section of the general account of the Forest

Nursery experiments now in course of preparation by the Chemistry Department as a Forestry Commission Bulletin. (J. B. Goodey.)

Amongst several populations of *Aphelenchoides* which have been cultured for the past year or two on agar medium with fungus (*Altenaria tenuis*), two species have been distinguished which did not agree in morphological characters with any of the known species. These have been described and named *A. composticola* and *A. saprophilus* respectively. The former occurs commonly in mushroom compost, where it feeds on the mycelium and causes reduced yields of mushrooms. The second is a species which is commonly encountered in soil and decaying plant tissues, where it is evidently a fungal feeder. These two species are morphologically very close to each other and to *A. parietinus*. (Mary T. Franklin.)

A new species of *Paraphelenchus* has also been found in mushroom compost and the mushroom spawn nematode, *Ditylenchus* sp., previously confused with *D. destructor*, has been distinguished on characteristics of the tail, post-vulval sac and spicule. Descriptions of both will be published shortly. (J. B. Goodey.)

Ditylenchus sp., *Paraphelenchus* sp., *Aphelenchus avenae*, *Aphelenchoides saprophilus* and three undescribed species of *Aphelenchoides* have been cultured on mushroom mycelium (*Agaricus hortensis* Cooke) grown on malt agar plates, but attempts to culture *Aphelenchoides blastophthorus* and *Tylenchus* sp. were unsuccessful. Mushroom is a new host record for *Aphelenchus avenae* and *Aphelenchoides saprophilus*. Descriptions of the three new species of *Aphelenchoides* are being prepared.

For further studies, large populations of various saprophytic nematodes are being cultured on Nigon's agar medium seeded with baker's yeast. Species successfully cultured include *Acrobeloides* sp., two species of *Caenorhabditis*, three species of *Diplogaster*, *Diploscapter* sp., *Eucephalobus* sp., *Panagrellus redivivus*, *Panagrolaimus rigidus*, *Pelodera* (*Cruznema*) *lambdiensis*, *Plectus* sp. and *Rhabditis* (*Rhabditella*) *axei* (D. J. Hooper).

In collaboration with Mr. F. C. Wood of Darlington & Sons Ltd., Worthing, experiments were conducted on the irradiation of infested mushroom compost with gamma-rays. Doses lying between 48,000 and 96,000 reps caused failure to reproduce in both *Ditylenchus* sp. and *Rhabditis* spp. (J. B. Goodey.)

Studies on the biology, morphology and host ranges of *Anguina* spp., *Ditylenchus radicicola* and various races of *Ditylenchus dipsaci* are continuing.

In conjunction with the National Institute of Agricultural Botany, Cambridge, seventeen winter oat varieties were tested for susceptibility to *D. dipsaci*. (J. B. Goodey and D. J. Hooper.)

Root-knot Nematodes

A start has been made on a survey of the species of *Meloidogyne* occurring in England and Wales. As a result of a request to the National Agricultural Advisory Service, specimens have been received from seventeen sources, both from glasshouses and out-of-doors. Seven of them from field crops and out-door nursery crops

contained *M. hapla*, and this species occurred also in two glasshouses. Of the other glasshouse crops four were infested with *M. incognita* var. *acrita* and two with *M. incognita*. Two populations were not identified and are being kept going in the greenhouse for further examination.

Populations of root-knot nematodes derived from single females of three species of *Meloidogyne* have been started in order to make observations on the variability of certain morphological characters useful in identification of the species. The populations are now in their third generation. (Mary T. Franklin.)

A list of plants resistant to *Meloidogyne* spp. has been compiled from the literature published during and after 1949. (D. J. Hooper.)

Cyst-forming Nematodes of the Genus *Heterodera*

Potato-root eelworm (Heterodera rostochiensis *Woll.*)

The results of two rotational experiments, one on a farm near Outwell and the other at Rothamsted, are undergoing analysis. Observations on population changes of potato-root eelworm on the Kirton Experimental Husbandry Farm are continuing. The first trial investigated the effects of D-D injection at the rate of 400 lb./acre in the framework of a six-course rotation of potatoes. In this silt soil a significant reduction in the field population of potato-root eelworm in terms of encysted eggs after the last potato crop appears to have been achieved only by four and five successive annual injections of D-D. (C. C. Doncaster.)

Investigation of the errors associated with field sampling have been made in conjunction with M. H. Westmacott of the Statistics Department. The aim has been to assess the magnitude of within-field variability which the methods of sampling in current use ignore. The results indicate that variability between the sampling points from which cores are taken to make up a composite bulk sample is much greater than that within points. Theoretical minimum errors corresponding to bulk samples composed of different numbers of cores have been calculated from the data, and these indicate the limits of accuracy obtainable by this method.

Direct comparisons between oxygen uptake and carbon dioxide production of cysts, eggs and larvae indicate that both cyst walls and egg shells tend to limit the passage of these gases and thus inhibit respiration. Experiments on the effect of root diffusates on respiration are in progress, but are not sufficiently advanced for any conclusions to be drawn.

The effect of ethylene dibromide on the hatchability of encysted eggs has been investigated. Fumigation reduces hatchability and modifies the form of the hatching curve by increasing the time necessary to attain the point of inflection, so that direct comparison between the hatch from control and from fumigated cysts is difficult unless the hatching test is carried on to completion. The shift in the point of inflection is less if cysts are allowed to stand for several months before testing, but even then it is inadvisable to draw conclusions from tests continued for a short, fixed time. (D. W. Fenwick.)

Investigation of the chemical nature of the hatching factor has continued in collaboration with A. J. Clarke of the Biochemistry Department. Five hundred gallons of root diffusate were collected between March and November from five plantings of potatoes in pots. Most samples were highly active, having L.A. values in excess of 3·5. The active factor was extracted after acidification with hydrochloric acid and adsorption on charcoal. Elution from the charcoal with hot acetone gave recoveries of between 30 and 60 per cent of the active principle if done within a few days of collection. Some loss of activity occurred, if elution from the charcoal was delayed, which indicates breakdown of the factor on the stored charcoal samples. This, and breakdown in acetone solutions, is under investigation.

The monitoring of diffusate production and the bioassay of chemical fractions in connection with the above work necessitated the conduct of hatching tests on more than 10,000 batches of 100 cysts each, each test lasting three weeks. (Elizabeth Widdowson.)

Potato-root eelworm has been successfully cultured in excised tomato roots growing in tissue culture. Tomato seeds, sterilized with bleaching-powder solution, are germinated in culture tubes on White's nutrient agar medium, and the root tip is removed and grown in flasks containing White's plant-culture solution. Growth is rapid, and many new root tips are produced each week. Although it is possible to hatch sterilized eggs aseptically to produce sterile larvae for inoculation, equally satisfactory results are obtained by introducing eggs sterilized with hydrogen peroxide directly into root cultures in tubes of nutrient agar. Evidently the hatching factor is produced by excised root tips, for hatching occurs very rapidly. Larval penetration of the roots begins after about 7 days, but only a small proportion of the available larvae succeed in gaining entry. Possibly this is due to local anaerobiosis, since larvae collect in dense clusters around the most attractive parts of the roots, particularly near root tips and the points of origin of lateral rootlets. Within the roots development proceeds normally and adult females burst through the surface of the cortex about 21 days after inoculation. Males are formed, but the right conditions for mating may not exist. Attempts to overcome this difficulty and to breed the parasites through several generations are being made in sterile sand cultures. (D. W. Fenwick and Elizabeth Widdowson.)

Work on biotypes of potato-root eelworm capable of breaking the resistance of crosses between *Solanum tuberosum* ssp. *tuberosum* and *S. tuberosum* ssp. *andigena* has been continued. A further twenty-five populations have been tested, of which only eight were non-aggressive. *S. vernei* proved resistant to all these populations and to twelve others as well. Cysts produced on resistant plants in 1956 were used to inoculate pots in 1957, which were again planted with resistant tubers, Arran Banner tubers being used as controls. The proportion of resistance-breaking females in the various populations increased markedly, even in the group which in 1956 were classified as non-aggressive. This indicates that when new potato varieties with resistance based on the dominant gene H from *S. andigena* are grown in the field, they may be heavily attacked in some fields and more or less immune in others. In the latter fields

they will cause a reduction in the population level at first, but repeated cropping with a resistant variety of the same type may lead to a change in the nature of the population such that immunity will be lost. No estimate can yet be given of the number of plantings necessary to bring about this change. (F. G. W. Jones.)

Cereal-root eelworm (Heterodera major)

One hundred and twenty species and varieties of oats from Europe and Africa were tested in soil infested with cereal-root eelworm for the presence of cysts on the roots. Thirty-five plants showed promise of resistance, in that very few or no cysts were seen on them.

A comparison of the rate of hatching from cysts in fallow soil with cysts in soil growing oat plants showed that cysts in fallow soil did not empty as quickly as the cysts in soil with plants. The difference was not great, but it suggests that oat roots may liberate a hatching factor into the soil.

The long-term experiment at Stoke-on-Tern has been completed. A test crop of oats was grown over the trial area that had been sown (for three years previously) with plots of oats, wheat, barley and rye. Only the plots previously down to autumn-sown rye and autumn-sown wheat which had received an annual application of fertilizer gave a good crop of oats; all other plots were poor, those after oats being complete failures. (J. J. Hesling.)

Pea-root eelworm (Heterodera göttingiana)

A detailed population experiment was set up using six infestation levels, ranged in a geometric series rising to 98 larvae/g. of soil, and six hosts, viz., field bean, " Windsor " broad bean, " Longpod " broad bean, " Kelvedon Wonder " pea, " Harrison's Glory " pea, " Lincoln " pea. The eelworm had little effect on the beans, judged by measurement of the plant weight, plant height and yield of seed, but its effect on the peas was marked, especially on their yield, which was reduced to less than 25 per cent of the control. Soil population counts have not yet been attempted, because it has been found that a special technique was required to ensure complete extraction of cysts from soil. The cysts remain embedded in the host-plant roots, which must all be recovered. At present the percentage loss of cysts in rootlets retained in the various stages of cyst extraction is being investigated, as is a method of digesting the rootlets in a cellulose enzyme 19AP, to release the embedded cysts.

Test of root diffusates from trefoil, lucerne, alsike, red clover, giant sainfoin, wild white clover, cultivated white clover, common sainfoin and garden pea showed that only diffusate from garden pea produced hatching at a higher level than the soil water control. (J. J. Hesling.)

Cabbage-root eelworm (Heterodera cruciferae)

Previous study of the morphology of the cabbage-root eelworm by means of dead permanent mounts has been supplemented by examination of living specimens. A series of photographs has been obtained of the development of a young fourth-stage male within the third-stage cuticle. Coiling and uncoiling movements were observed

followed by rapid increase in body length and decrease in diameter resulting 24 hours later in four-fold flexure within the ensheathing cuticle.

Outdoor experiments to determine the time taken to complete one cycle of development were made using rape as the host plant. Plants invaded in January gave rise to cysts in which embryonated eggs appeared in July, a period of 29 weeks. Invasion of plants in subsequent months led to the formation of embryonated eggs in successively shorter periods of time, the shortest period, 6–8 weeks, being required for plants invaded in June and July. From these later invasions embryonated eggs appeared in August. After July the period required for development began to lengthen. (C. C. Doncaster.)

Predators of root eelworms

Differences in the degree to which *Heterodera* populations increase when host crops are grown have been noted in different soils. These differences may be due to soil structure/moisture relationships or to the influence of various enemies, including soil Arthropods. A method by which relative densities of collembolid predators can be compared in bulk samples of different soils is being developed, and a comparison has been made of the *Onychiuris armatus* populations, from: (1) an Essex soil with *H. cruciferae* infestation which in 1956 caused a crop failure of spring cabbage; (2) the Rothamsted *H. cruciferae* plot where the nematode does not increase even under continuous cropping; and (3) a flourishing Rothamsted *H. rostochiensis* plot. From 3-gallon soil samples from each of these sources, *O. armatus* was recovered in the proportions of 14 : 232 : 441.

New predators found include three or more species of Staphylinid beetle, two species of Myriapod and two species of mite. A method is being developed whereby the proportions of *Heterodera* populations devoured by soil meiofauna can be assessed. In a preliminary trial, in which potatoes infested with potato-root eelworm were used, an average of 22 per cent of newly formed females were destroyed. (C. C. Doncaster.)

Movement and Activity of Nematodes in Soil

Various aspects of the movement of eelworms in soil have been studied, especially in relation to the physical environment. Experiments with larvae of the beet eelworm, *Heterodera schachtii*, have shown that there is an optimum pore size for movement. Studies on the movement of beet eelworm larvae in water films indicate that there is also an optimum film thickness for progression. A comparative study of the beet eelworm and the stem eelworm *D. dipsaci* suggest that there is a simple relationship between body length, particle size and speed. Later experiments with eelworms of different length and activity tend to support the hypothesis that for maximum mobility the longer eelworms require correspondingly larger soil particles. The influence of water percolation into the soil on the movement of eelworms is also being investigated. Experiments on the attraction of eelworms to roots indicate that both the beet eelworm and the oat eelworm (*H. major*) are attracted to roots

and that the nature of the attraction is an orientation to a concentration gradient of some chemical liberated by the roots. Relationships between rate of emergence from cysts and attraction in the presence of host roots in sand at different hydrostatic pressure deficiencies suggests that concentration of this hypothetical chemical factor is important. (H. R. Wallace.)

Special Photographic Techniques

A simple reflex viewing device and an exposure metering device have been made in collaboration with the Maintenance Department for cinematography. A film has been made from which H. R. Wallace was able to study the mechanics of nematode locomotion in various media. Still and ciné records of predators feeding on nematodes and films of oesophageal movements of various nematodes, the movement of larvae within eggs and within the uterus of *Pelodera* sp. have also been made. (C. C. Doncaster.)

INSECTICIDES AND FUNGICIDES DEPARTMENT

C. Potter

During the current year Miss Janet Samuel left the department and K. A. Jeffs has been appointed in her place. A. J. Arnold has been seconded to the West African Cocoa Research Institute for 3 years. M. Das was awarded the Ph.D. degree of the University of London and has returned to India. R. A. Harrison completed a stay of 6 months and returned to New Zealand. H. J. Smith, who had just joined the Pyrethrum Board of Kenya, spent approximately 4 months in the department with M. Elliott, being trained in the chemistry of the pyrethrins. E. Mastrandreou arrived from Greece to work in the department.

M. Elliott attended the 16th International Congress of Pure and Applied Chemistry in Paris, and A. H. McIntosh, P. H. Needham and C. Potter attended the 4th International Congress of Plant Protection in Hamburg. After the Congress A. H. McIntosh and C. Potter visited a number of laboratories in Germany and Holland.

In collaboration with the Entomology Department a course on insecticides and applied entomology was given on behalf of the British Council. Representatives from Denmark, France, Germany, Italy, Lebanon, the Netherlands, Portugal and Sweden attended the course.

Two of the new constant-temperature–constant-humidity rooms came into operation during the year and have proved very useful. There are difficulties in operating the other two, and work has not yet begun on the constant-environment plant-growing rooms.

The new glasshouse accommodation has nearly been completed.

Insecticides

Time, temperature and toxicity of insecticides

M. Das, under the supervision of A. H. McIntosh and with his help, has finished his work on this subject.

More results have been obtained by the general method, which is described in *Rep. Rothamst. exp. Sta. for* **1956**.

With toxaphene on *Tribolium castaneum*, the temperature coefficient between 10° and 28° C. was $> +12$ on the first day after treatment; it decreased to zero on the 9th day, and to $-3{\cdot}9$ on the 24th day after treatment. This is similar to the previous results with toxaphene on *Tenebrio molitor*.

With " Valone " on *Musca domestica*, the temperature coefficient between 10° and 28° C. was $> +2{\cdot}6$ two hours after treatment; it had decreased to zero by the 12th hour, and to $-1{\cdot}6$ on the 5th day after treatment. This is similar to the previous results with *T. castaneum*.

With α-chlordane on *M. domestica*, the temperature coefficient

between 10° and 28° C. was +6·1 on the first day after treatment; it decreased to zero on the 3rd day after treatment, but did not become negative, as in the previous tests with *T. castaneum* and *T. molitor*.

With "Dimetan" on *M. domestica*, the temperature coefficient between 10° and 28° C. was —1·6 on the first day after treatment. After this it remained unchanged, even on the 5th day. This is similar to the previous results with *Oryzaephilus surinamensis*.

The negative coefficients previously found for DDT on various species in the range above 10° C. were either constant in size (*T. castaneum* and *M. domestica*), or increased in size as time passed (*T. molitor* and *O. surinamensis*). The positive temperature coefficient found for DDT on *T. molitor* in the range below 6° C. has been found to change in size as time passes. Thus, the temperature coefficient between 2° and 6° C. was +45 on the 12th day after treatment, +3·8 on the 16th day and +1·5 on the 20th day. It has not been possible to find a positive temperature coefficient for DDT on other species; *T. castaneum*, *O. surinamensis* and *M. domestica* are all much more sensitive to cold than *T. molitor*.

In considering the results given above, and in last year's report, it may be said by way of summary that when single measured doses are applied in contact tests there is a general trend: the temperature coefficients are either negative or change, as time passes, in the direction positive to negative. This applies to tests of 2-bromomercurithiophen, α-chlordane, DDT, "Dimetan", toxaphene and "Valone", tested on adults of *T. castaneum*, *O. surinamensis*, *T. molitor* and *M. domestica*. It does not apply to tests with rotenone. The temperature coefficient of any one poison on any one species seldom has any single value. In many cases it is not even enough to say that the temperature coefficient is "positive" or "negative". The effect of time on temperature coefficient must be specified. If the time between treatment and counts of kill is long enough, the temperature coefficient may reach a steady value. This may be said to be the true temperature coefficient of the poison, and should be used when making comparisons between poisons.

Tests with DDT as a mosquito larvicide

Some tests have been made to find the temperature coefficient of DDT as a mosquito larvicide. Such tests have, in the past, usually been made by immersing the larvae in suspensions of DDT for the duration of the test. Temperature affects the activity of the larvae and causes them to take up more DDT at a higher temperature. This favours a positive temperature coefficient.

However, Das's tests have shown that if the larvae are immersed in the suspensions for a short time at 15° C. and are then removed to clean water at 15° and 28° C., a large negative temperature coefficient is obtained. As with other species, the effect of DDT on mosquito larvae is to some extent reversible. Larvae which are badly affected by treatment at 15° C. recover to some extent if placed in clean water at 28° C., but not at 15° C.

The results of these tests are in line with those in which single measured doses are applied to non-aquatic insects.

Effect of drugs on action of DDT

Sublethal doses of various nerve-stimulant and nerve-depressant drugs were injected into adult *T. molitor*, either before or after topical application of DDT. None of the treatments had any effect on the course of poisoning by DDT, nor on its temperature coefficient in the range 10–28° C.

The isolation and properties of insect esterases

K. A. Lord has continued his work on this subject. The acetyl choline hydrolysing enzyme obtained from *Blatella germanica* has been further purified by fractional precipitation with acetone in the cold, and an examination of its properties begun.

Although the preparation hydrolyses phenyl acetate to some extent, heat inactivation and mixed substrate experiments indicate that it is the cholinesterase which is responsible and not a separate enzyme.

The cholinesterase from the German cockroach is qualitatively similar to that obtained from houseflies and bees and the so-called true mammalian cholinesterase. It hydrolyses acetyl choline, propinyl choline, acetyl β-methyl choline but not butyryl choline or benzoyl choline. Further it is inhibited by high concentrations of choline-esters. Activity substrate concentration curves using both the Warburg and electrometric methods of titration resemble those obtained with human and housefly cholinesterase.

Determinations in the Warburg did not indicate any considerable activation by 0·33*M*-NaCl or 0·033*M*-$MgCl_2$ but rather a shift in the position of the curves to higher acetyl choline concentrations. In the presence of 0·33*M*-NaCl there was an indication of an optimum substrate concentration at $10^{-3}M$-AcClCl, but in the absence of added NaCl maximum activity was displayed at substrate concentrations ($10^{-4}M$) when determinations became unreliable. Using the electrometric method in the absence of salts, the cockroach cholinesterase showed maximum activity at substrate concentrations so low ($10^{-5}M$) that reliable readings were not possible.

It is estimated that the cockroach cholinesterase has an affinity for acetyl choline about ten times that of housefly cholinesterase.

Esterases in relation to the development of eggs of Pieris brassicae *and* Gryllus domesticus *and the toxicity of organophosphorus compounds*

Following up the work reported last year on the toxicity of TEPP to eggs of *Pieris brassicae*, C. Potter, K. A. Lord, D. V. Holbrook, S. R. B. Solly and F. Molloy have carried out more extensive investigations on the properties of the esterases of insect eggs, and the toxicity of further phosphorus insecticides has been examined under a range of conditions. Information on the ratio between the amount of poison which will allow development but will not allow hatching and that which will prevent development and on the changes of resistance as development proceeds has been sought, since when it is correlated with the physicochemical properties of the poisons it may give an indication of the esterases involved in the poisoning.

A simpler technique of applying poisons to the eggs has been evolved as a result of finding that the wetter Tween 20 was non-

toxic to *P. brassicae* eggs. The eggs are simply left standing in a solution of the poison in 0·1 per cent Tween for 5 minutes.

This method has been used to determine the toxicity of "Dipterex" and paraoxon to newly laid eggs. Both of these compounds, like TEPP and many other insecticides, may allow the embryo to develop and yet prevent the egg from hatching. However, the ratio of the dose to prevent visible development to that which just stops hatching is very much greater in the case of "Dipterex" and paraoxon (>100 ×) than in the case of TEPP (<30 ×). The dose of paraoxon which prevents development is, however, less than that required for TEPP. It has not been determined for "Dipterex" owing to lack of solubility.

"Dipterex" and paraoxon have also been applied at various stages of development and the concentrations determined which prevent hatching. These show only small changes (2–4 ×). Perhaps it is significant that the eggs were most susceptible half-way between laying and hatching. This contrasts with the susceptibility to TEPP, which increases slowly until the egg is half-way through development, when it increases more rapidly. The overall change is about thirty times.

Again, with a view to finding out whether the reaction responsible for death may occur at an early stage of development, we have attempted to examine the penetration and reaction of organophosphorus insecticides by treating newly laid *P. brassicae* eggs with lethal amounts of paraoxon and then washing with water or a cholinesterase reactivator. Diacetyl monoxime (DAM) was chosen because of its low toxicity to eggs. Washing the eggs soon after poisoning results in a large reduction in toxicity. Our results indicate that the bulk of the poison is no longer readily removed by washing after the first 10–20 hours. Up to 3 days at 15° C. washing with water causes the same reduction in toxicity as a DAM solution. Subsequently, however, the effect of washing with water slowly decreases, whilst the DAM has about the same effect throughout.

Further observations on esterases hydrolysing acetyl choline and phenyl acetate during the development of *Pieris brassicae* have been made, and the investigations have been extended to include the hydrolysis of triacetin. The results confirm those previously reported and show that enzymes hydrolysing triacetin are present throughout all stages of development.

Although work with crude breis may be misleading, it has been considered worthwhile to make some rather more extensive studies on the hydrolysis of triacetin, phenyl acetate and acetyl choline at two selected stages, soon after the eggs are laid and shortly before hatching (0–12 hours and 5 days old at 20° C.).

We have investigated the effects of salts (sodium chloride, magnesium chloride, calcium chloride), substrate concentration and pH. These results, together with those obtained from development studies, lead us to believe, that in the main, different enzymes are responsible for the hydrolysis of each of the three substrates. It also seems likely that the enzymes responsible for the hydrolysis of both phenyl acetate and triacetin change as development of the egg proceeds. These impressions are supported by inhibition data obtained using three insecticides, TEPP, paraoxon and "Dip-

terex ". The three poisons behave in qualitatively similar ways except for certain anomalies which may be explained on the basis of their differing chemistry.

The three compounds inhibit cholinesterase non-competitively, and the extent of the inhibition increases with the time elapsing before the addition of substrate. The same phenomenon has been observed with the inhibition of the phenyl acetate hydrolysing enzyme present in the young eggs, but in the older eggs the inhibition of this esterase appears to be competitive and independent of time. The enzymes hydrolysing triacetin are much less susceptible to inhibition than the others.

Similar experiments have been commenced with *Gryllus domesticus* eggs, but have not progressed so far owing to lack of adequate supplies of eggs.

In addition to the biochemical studies on the effect of organophosphorus compounds on insect eggs, histochemical techniques have been investigated for the localization of cholinesterase in insect eggs and the determination of the effect of treatment of the eggs with organophosphorus compounds on cholinesterase *in situ*. Miss Molloy has been chiefly concerned in this work.

Biochemical methods of studying *in vivo* enzyme inhibition suffer from certain disadvantages owing to the mixing of tissues, so that it is uncertain whether the inhibition measured is occurring *in vivo* or *in vitro*. Histochemical methods do not give rise to the same degree of cross-contamination.

Histochemical methods of demonstrating cholinesterase activity depend on the production of a coloured compound at the enzyme site. Very precise localization may be obtained, and the method may be used to detect very small amounts of the enzyme.

When the techniques were applied to insect material, difficulty was encountered in cutting frozen sections. Some material, however, was kindly freeze-dried and embedded by Dr. Pratt at the Maudsley Hospital, and it has proved possible to cut satisfactory sections of this.

Preliminary work was carried out on mouse muscle tissue, so as to gain experience of the staining procedures and frozen-section cutting. Sharply localized staining of the sites of cholinesterase activity was obtained by a simplification of the technique of Koelle (*J. Pharmacol.* 1957, **103**, 153).

In the application of this method to *Pieris brassicae* L. eggs, these were not sectioned, but the embryos were incubated whole, after the removal of the choria, vitelline membranes and residual yolk.

The younger embryos (0–5 days old) were very fragile. The best staining results were obtained with embryos 6–7 days old. The staining is apparently entirely confined to the central nervous system, and is often noticeably darker in the " inner core " or " neuropile " of the ventral nerve cord. Staining of older embryos (7–9 days) is patchy, and is often associated with damage, suggesting increasing impermeability of the cuticle and the nerve sheath.

Pre-treatment of the embryos with trypsin improves the staining. Further enzymes are in the course of investigation in this respect.

General, diffuse staining, indicating the presence of non-specific esterases, has been obtained in whole embryos of *P. brassicae* after incubation with indoxyl esters.

Preliminary experiments on the eggs of *P. brassicae* treated with TEPP at 0 days old indicate that some inhibition of acetylcholinesterase or a precursor had taken place.

Toxicity of organophosphorus compounds to various strains of Musca domestica

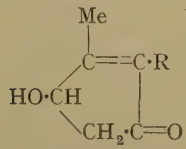
K. A. Lord, D. V. Holbrook and T. Doherty have worked on this subject. In view of the lack of resistance of the strains of housefly (79 and 150) supplied by Dr. Keiding reported last year, an exchange of material was arranged with Dr. Keiding. The resistance of the adults of the strains in both countries appear to have lost the resistance which was originally reported.

The attempt to breed resistant houseflies by incorporating paraoxon in the larval medium has been abandoned owing to breeding difficulties which were encountered with the selected flies. In connection with this a simple larval dipping test was evolved. This test has been applied to the larvae of the various strains of flies in the department.

No great differences were noted in the average level of resistance of the larvae from the different strains. It was, however, noted that whilst the larvae from the strain supplied by Dr. Busvine and strain 150 supplied by Dr. Keiding were all killed by 0·003 per cent paraoxon, 20–30 per cent of the larvae from the normal strain and 79 strain survived concentrations ranging from 0·003 to 0·1 per cent paraoxon. 0·001 per cent paraoxon had no effect on the larvae from any of the strains tested.

Pyrethrins and related compounds

M. Elliott has studied some of the properties and reactions of pyrethrolone (I), the alcoholic constituent in pyrethrins I and II, which supply most of the insecticidal activity in preparations from *Chrysanthemum cinerariaefolium* flowers.



(I) R, $CH_2CH^{c}{=}CH{\cdot}CH{=}CH_2$

(II) R, $CH_2CH^{c}{=}CH{\cdot}Me$

(III) R, $CH{=}CH{\cdot}CH{=}CH{\cdot}Me$

(*a*) Previous workers have obtained a mixture of pyrethrolone (I) and cinerolone (II) by shaking the semicarbazones for a long time with aqueous potassium hydrogen sulphate. The two closely boiling alcohols were separated by distillation of their acetates, followed by hydrolysis or, less satisfactorily, by fractionation of the free alcohols. In both these methods pyrethrolone, which is an unstable compound, rapidly decomposed in air and light, was obtained in an uncertain state of purity. Quantities of pure, naturally derived pyrethrolone were required for making relatively large amounts of pyrethrins I and II, of which sufficient were not available by synthesis or by chromatographic separation.

It has been found that pyrethrolone (I) and cinerolone (II) may be regenerated from their semicarbazones in 24 hours with dilute sulphuric acid, rather than by shaking for 6–18 weeks with potassium hydrogen sulphate solution. Moreover, both keto-alcohols form monohydrates. That from (+)-pyrethrolone is crystalline and may be purified by low-temperature recrystallization from ether. The hydrate is apparently stable for some days at room temperature and indefinitely at −20°. It has therefore been possible to determine the physical (including infra-red and ultra-violet spectra) and chemical properties of the keto-alcohol more precisely than before.

Pure (+)-pyrethrolone (from the monohydrate by removal of water *in vacuo*) has been esterified with naturally derived, purified, chrysanthemic and pyrethric acids, to provide supplies of pure pyrethrins I and II limited only by the amount of extract available for processing. These esters have been characterized by their physical (including absorption spectra and optical rotations), chemical and biological properties (toxicities to adult *Musca domestica* [by R. Sawicki] and to *Phaedon cochleariae* [by P. H. Needham]). In all cases the reconstituted esters have been found identical with fractions isolated from the natural material by displacement chromatography on alumina.* Although pyrethrins I and II have been reconstituted before, the methods used for isolating the keto-alcoholic fraction were more likely to produce molecular changes than those described here, and they have not previously been compared with esters obtained from natural sources under conditions unlikely to have produced any change in their constitution.

Using the reconstituted esters, a study of their decomposition in air and light has been started. Preliminary results indicate that, under these conditions, pyrethrin I ($C_{21}H_{28}O_3$) sets to a glass of composition $C_{21}H_{28}O_5$.

(*b*) Brown, Phipers and co-workers † showed that compounds of unknown constitution ($\lambda_{max.}$ 270 mμ) were formed when pyrethrum extract ($\lambda_{max.}$ 230 mμ) was heated to 200°. Through the kindness of Dr. R. F. Phipers and Mr. N. C. Brown, of the Cooper Technical Bureau, Berkhamsted, this phenomenon has been investigated in this department. In agreement with the prediction of these authors, it has been found to involve migration of the double bonds in the side chain of the pyrethrolone constituent of the esters into conjugation with the double bond in the *cyclo*pentenone ring (III). Development of a small-scale technique for following the reaction spectrophotometrically enabled it to be proved that only pyrethrolone and its derivatives produced the characteristic triple absorption maximum at 260, 270 and 280 mμ. The infra-red spectrum of the heated mixture of natural pyrethrins showed that the terminal methylene group frequency had disappeared. Thermally isomerized pyrethrolone methyl ether ($\lambda_{max.}$ 260, 270 and 280 mμ; $\lambda_{min.}$ 215 mμ) still contained a keto group (semicarbazone and 2 : 4-dinitrohydrazone) in a five-membered ring (infra-red spectrum); hydrogenation under mild conditions indicated two double bonds, and acetaldehyde was obtained by ozonolysis. Since (+)-pyrethrolone on isomerization

* Ward, J. (1953). *Chem. & Ind.*, 586.

† Brown, N. C., Hollingshead, D. T., Phipers, R. F. & Wood, M. C. (1957). *Pyrethrum Post*, **4**, No. 2, 13.

gave (—)-"*iso*pyrethrolone", double-bond migration to the optically active centre at C_4 cannot have taken place. Structure (III) is therefore proposed for the parent alcohol of the thermally isomerized compounds; the stereochemistry is at present unknown. It is the first example of a cross-conjugated ketone of this type (*Rep. Rothamst. exp. Sta. for* **1956**, p. 131); the carbonyl group appears to depress the intensity and not to affect the position of maximum absorption of the triene system. A study of the spectroscopic properties of these compounds, and of their derivatives, has been made.

Biological evidence obtained so far indicates that the ester of chrysanthemic acid with pyrethrolone (I) is 16 times as toxic as that from "*iso*pyrethrolone" (III) to adult *Phaedon cochleariae*.

R. Sawicki and P. H. Needham have carried out biological measurements of the activity of the isolated insecticidal constituents of pyrethrum flowers.

In the absence of a more suitable standard, a pyrethrum extract, which contained pyrethrin I and cinerin I, 13·1 per cent; pyrethrin II and cinerin II, 10·9 per cent: total pyrethrum 24·0 w/v. [P.B.K. modified Seil's method of analysis] was used. The extract served as a constant with which to compare the biological activities of the separated constituents. It was unsatisfactory because the activities relative to this standard depended on the proportions of active constituents in it, and tests against another extract with different proportions of constituents are likely to have given different results. Another disadvantage of using a pyrethrum extract as a standard is that the various methods of analysis of pyrethrum give different results, so that the numerical ratios expressing the relative potencies depend on the method of analysis used.

A comparison between the concentration of active constituent under examination and the concentration of total active constituents of the extract to produce the same biological response was made.

Two test insects were used, adult houseflies (*Musca domestica* L.) by R. Sawicki and adult mustard beetles (*Phaedon cochleariae* F.) by P. H. Needham. With houseflies insufficient knowledge of the influence of the age of the test insect and of the length of the period between treatment and inspection on both the absolute and relative figures for knockdown or paralysis and toxicity has handicapped the work. Considerable information on both these points has been obtained, and is described in the section on bioassay, where the full technique is given.

(*a*) Tests with adult houseflies *Musca domestica* L.:

(1) *Pyrethrin I.* Preliminary determinations were made using small quantities of pyrethrin I obtained by Dr. Spickett of the Tropical Products Institute from the natural material using the chromatographic method of Ward. The main work was carried out on reconstituted material prepared by M. Elliott of this department (see pp. 136–138) after it had been shown that it produced the same biological effects as the material supplied by Dr. Spickett.

Five comparisons were made with after treatment conditions of 20° C. and 80 per cent relative humidity and an inspection time of 48 hours. It is considered that with an inspection

time of 48 hours the figures indicate relative toxicity rather than relative paralysis or knockdown.

The pyrethrin I was 1·09, 0·87, 0·89, 0·94 and 1·069 times as toxic as the extract.

In tests where the inspection period was 24 hours, i.e., where knockdown was being measured rather than kill, pyrethrin I was found to be 0·72 and 0·69 times as effective as the extract on young flies and 0·93 times as effective on old flies.

(2) *Pyrethrin II.* All the pyrethrins II material was prepared by M. Elliott. Only preliminary figures have been obtained so far. They indicate that under the same conditions as the test with pyrethrin I, pyrethrin II gives a similar kill to pyrethrin I weight for weight. However, in contrast to pyrethrin I, pyrethrin II appears to have a greater knockdown effect than the extract when measured after 24 hours.

(3) *Cinerin I.* The cinerin I used so far was obtained from Dr. Spickett; it is not definitely known how pure this material is. Preliminary experiments under the same conditions as the preceding tests indicated that when measured at the LD50 level, cinerin I was much less toxic than the pyrethrum extract to young flies as shown by a 48-hour inspection.

A comparison after 24 hours during preliminary tests indicated that the knockdown effect was very much less than that of the pyrethrum extract when measured at the LD50 level.

Using young flies, the probit lines for cinerin I were not parallel with those of the extract. The extract gave steeper slopes. In these preliminary experiments with younger flies the insects treated with cinerin I showed little or no recovery from initial knockdown, and the kill increased with time; this is in contrast with pyrethrin I, pyrethrin II and the extract, where considerable recovery from initial paralysis occurred.

(*b*) Tests with adult mustard beetle *Phaedon cochleariae*:

A topical application method was used with this species also; the following were the conditions of test.

A 0·001-ml. drop of an acetone solution was applied to the ventral surface of the thorax of each beetle. Two replicates of twenty-five beetles were treated at each concentration of the poisons used. After treatment storage was in " petri " dishes, with glass lids, at a temperature of 20° C. and 55 per cent relative humidity. The beetles were not fed after treatment. Mortality counts were made 48 hours after treatment. At this time mortality and not knockdown was being estimated.

The reconstituted pyrethrin I prepared by M. Elliott was found to have exactly the same toxicity to mustard beetles as the chromatographed material from Dr. Spickett, the probit lines being parallel and the LD50 under the conditions of the experiment being 0·0008 per cent w/v.

The pyrethrin I prepared by M. Elliott was used for the subsequent tests.

In three comparisons where the data were satisfactory, pyrethrin I was found to be from approximately twice, to approximately three times, as toxic as the pyrethrum extract.

In two tests pyrethrin I was found to be approximately three times as toxic as pyrethrin II. The exact figures for these tests are given in Table 1:

TABLE 1

	Pyrethrin I		Pyrethrin II		Extract	
Date	LD50, % w/v	Relative potency	LD50, % w/v	Relative potency	LD50, % w/v	Relative potency
15.10.57	0·0007	100	—	—	0·002	35
23.20.57	0·0007	100	—	—	0·0014	50
19.11.57	0·0006	100	0·0018	33	0·0010	60
6.11.57	0·0004	100	0·0015	27	—	—

When the tests on the houseflies are compared with those on mustard beetles it appears that the relative as well as the absolute toxicity of the active constituents depend on the test species. Thus pyrethrin I has approximately the same toxicity as both the extract and pyrethrin II to young houseflies, but it is between two and three times as toxic as the extract and about three times as toxic as pyrethrin II to mustard beetles. The importance of using more than one test species before coming to any general conclusions is here emphasized.

(*c*) Temperature effects and synergism:

R. Sawicki has worked on this subject. A considerable amount of work was done before the factors in the technique that affect the results were worked out sufficiently to give reliable figures.

The object of the present study was to determine how temperature affects synergized pyrethrum extracts in comparison with extracts that have no synergist. At 25° C. it appears that with the extract alone there is a considerable recovery after 48 hours from the knockdown recorded after 24 hours; in the presence of synergist there is little recovery from the initial knockdown.

It also appears that for the extract alone the temperature coefficient of knockdown may be greater than the temperature coefficient of kill.

The time taken for the completion of the knockdown effect and for the completion of the toxic effect (end point) varies with the temperature of after treatment, and the correct inspection times for the different temperatures must be used.

Toxicity and persistence of insecticidal deposits

Effect of additives on DDT emulsions. J. Ward has worked on this subject. The rate of evaporation of DDT from deposits on glass plates was measured using the ventilated cabinet described in *Rep. Rothamst. exp. Sta. for* **1956.**

The evaporation from deposits of various types, produced by spraying plates with emulsions containing resinous or oily additives, was compared in this way. No large differences in rate of evaporation were found. In particular, formulation of DDT with Arochlor resin did not reduce its rate of evaporation, though Arochlor is reported to reduce the rate of evaporation of BHC. It is intended

to use the apparatus to study the evaporation of insecticides other than DDT.

Much of the work on insecticidal deposits was devoted to the study of bioassay methods for the determination of toxicity and persistence which is described in the next section.

Bioassay Techniques

Bioassay of contact toxicity of insecticide deposits. (1) Adult *Tribolium castaneum.* Efforts by J. Ward and E. M. Gillham to trace the causes of the unreproducible results obtained when deposits of DDT on glass plates are tested for contact activity, using *Tribolium castaneum* (Herbst), have continued. In experiments in which the insects have been confined on the deposit singly instead of in groups of ten, the variability of the results was much reduced. This may have been because a larger area of the deposit was included in a single sample, and therefore irregularities in the deposit had less effect on the result, or it may have been because the variability is connected with an effect of the insects on one another when exposed in groups. More reproducible results were obtained when deposits of liquid droplets were used, instead of crystals; this indicates that the variability is at least in part due to irregularities in the nature of the deposit. A very large amount of data has now been collected, and work with *T. castaneum* has been suspended until the results have been examined statistically.

(2) Adult *Musca domestica.* The method of assessment mentioned in the last Annual Report, in which flies are confined between two glass plates so spaced that the flies are forced to crawl on the one bearing the deposit, has several defects. In particular, the flies are held on the deposit in an unnatural attitude, and the method is not applicable to deposits on irregular surfaces. Alternative methods of persuading the flies to remain on the surface under test are being examined; of these, the most promising involves the use of a temperature gradient.

Bioassay of contact toxicity of pyrethrum type molecules with adult Musca domestica

For the purpose of his work on the insecticidal action of the constituents of pyrethrum flowers R. Sawicki adopted a topical application method with adult houseflies (*Musca domestica*) as test subject. He has studied some of the factors on the technique influencing the results. The technique finally elaborated is as follows. Female flies only are used for the tests; the insects were sorted out 24 hours before dosing in a cooling cabinet, and were kept in Petri dishes (fifteen flies per dish) which were covered with terylene gauze. The flies were preconditioned for 24 hours at the temperature and humidity at which the experiment was going to be carried out. During that period they were given a paste made of dried milk with water and a sugar solution. The flies were then knocked down by cooling for a very short period during dosing, and a measured drop (1 microlitre) of Analar acetone containing the substance dissolved, was then applied to the thoracic sternum of each insect. Food was withdrawn at the time of dosing, and no food was given during the host treatment period. The insects were replaced into the cabinet in

which they had spent the preadaptation period, and were subsequently inspected 24 and 48 hours after dosing. Sometimes when mortality in controls did not exceed 10 per cent, inspections were carried out on the third day after dosing.

In order to find not only the knockdown power of the substances investigated, but also the final kill, it was necessary to keep the flies alive for as long as possible. This was not very easy, because in order to prevent complications the insects had to be kept without food during the experiment. Flies usually do not live very long at high temperatures when starved, and it was found that they had to be fed after sorting. Flies would not survive 24 hours at 25° C. if they were not fed after having been in the cold cabinet for periods of up to 4 hours. It was therefore decided to supply the insects with food during the preadaptation period and remove it at the time of dosing.

Apart from those standardized in the technique as described above, two factors were found to have a marked influence on the results. The first was the inspection time, and the second was the age of the fly. If short inspection times were given, knockdown was measured and not kill. The relation between knockdown and kill varied with the chemical under investigation. If the inspection time increased sufficiently to give a reliable record of final kill the flies are liable to die naturally. The addition of food during the after-treatment period would prolong the life, of the flies, but would provide a considerable added complication in assessing the results. After investigation it was found that the life of the flies without food could be prolonged by giving the shortest possible exposure to cold in the sorting cabinet and by keeping the flies after treatment at a high humidity.

For a time it was believed that young flies 1–2 days old would have a longer post-treatment life, but this does not appear to be necessarily true, and it seems that older flies may be preferable because, for a given degree of standardization, their resistance is less variable.

Using pyrethrum extract with after treatment conditions of 20° C. and 80 per cent relative humidity and an inspection period of 48 hours, 1-day-old flies were 1·68 times as resistant as 2–3-day-old flies and 2·45 times as resistant as 3–4-day-old flies. At present the age of the flies that it is best to use has not been finally decided.

Detection and identification of toxic substances in poisoned bees

P. H. Needham and J. Ward collaborated in this work. During the summer, ten samples of poisoned bees were received from the National Agricultural Advisory Service for testing for the presence of insecticide. Of these, three were found to contain benzene hexachloride, two contained an organophosphorus type of insecticide, one contained insecticidal material which could not be identified, and in four samples no insecticidal material could be found. Four of the samples, all despatched between 12 June and 5 July, were thought by the beekeepers to have been poisoned by organophosphorus insecticides.

Some improvements in the methods of detection and identification were made so that they were less laborious than those used last

year. The insecticides were separated from the bulk of the lipoid material in the bee-extracts by evaporating the extracts to dryness in the presence of a coarse grade of Celite, so as to deposit the involatile matter in a thin film on the grains. The Celite was then washed on a porous glass filter with increasing strengths of aqueous alcohol or acetone. All insecticides could be washed out in this way without removing much of the waxy material. The presence of organophosphorus insecticides was shown by a spot-test in which the insecticide, after suitable chemical treatment where necessary, inhibited esterase applied to filter-paper. Unaffected esterase was then made visible by a colour reaction. The problem of further identification of the organophosphorus compounds by their physical and chemical properties is difficult, because many of them are known to be metabolized by the insect into various esterase-inhibiting compounds.

Bioassay tests were used as a general method of detection of the presence of insecticidal material. The mosquitoes necessary for this work (*Aëdes aegypti*) are now being reared in the department, and a continuous supply of larvae is available.

As was mentioned last year, a more satisfactory method has been adopted for conducting the bioassay tests on the extracts from the bees. The technique is a modification of that described by Burchfield *et al.* (*Contr. Boyce Thompson Inst.* **17** (1), 57–86). This makes use of the inhibition of the negative phototaxis of the larvae by poisons in order to sort the affected from the normal individuals. The method is very sensitive, but difficulty is being experienced from the presence in the extracts of toxic substances other than those we are trying to detect. It is thought that these are due to toxic impurities present in some of the solvents used in the extraction. These are concentrated when the extract is concentrated by evaporation. The problem is being investigated, and we hope to overcome the difficulty in the near future.

Insect rearing

The following insects were reared in the department during the year:

Plant feeding

HEMIPTERA	*Megoura vicae* Buck.
	Aphis fabae Scop.
	Acyrthosiphon pisum Harris.
LEPIDOPTERA	*Pieris brassicae* L.
	Diataraxia oleracea L.
COLEOPTERA	*Phaedon cochleariae* F.
DIPTERA	*Leptohylemyia coarctata* Fall.

Stored product, domestic and medical

ORTHOPTERA	*Blatella germanica* L.
	Blatta orientalis L.
	Periplaneta americana L.
	Gryllus domesticus L.
LEPIDOPTERA	*Achroia grisella* Fabr.

COLEOPTERA	*Oryzaephilus surinamensis* L.
	Oryzaephilus mercator Fouv.
	Tribolium castaneum Hbst.
	Tribolium confusum Duval.
	Tenebrio molitor L.
	Trogoderma granarium Everts.
DIPTERA	*Aëdes aegypti* L.
	Drosophila melanogaster Meig.
	Musca domestica L.

The rearing of cultures of the following insects has been discontinued: *Actias selene* Hubner; *Ephestia kühniella* Zell.; *Calandra granaria* L.; *Dysdercus fasciatus* Sign.

Diapause in Leptohylemyia coarctata *Fall.*

Experiments described in *Rep. Rothamst. exp. Sta. for* **1956** were repeated by M. J. Way, and it was confirmed that diapause in its later stages is terminated rapidly by exposing the eggs to −20° to −24° C. Such low temperatures have no effect during the first 4–8 weeks of diapause. This and other evidence suggest that the very-low-temperature treatment releases a growth hormone which has accumulated during the earlier stages of diapause.

Eggs laid in August 1956 were kept first at 20° C. and then at −2° C. until diapause was complete. Batches were then kept at −2°, −6° and −18° C. Eggs removed from all temperatures to 20° C. hatched normally in May 1957, but subsequently, viability decreased except at −6° C. At this temperature over 90 per cent of eggs hatched in October 1957, 13 months after they were laid. The young larvae were able to attack wheat and apparently develop normally. Thus it is possible to keep eggs viable until those from the next generation can be induced to hatch by the low-temperature treatment.

Wheat-bulb fly (Leptohylemyia coarctata *Fall.*)

R. Bardner continued to carry out box and field experiments on insecticidal control of wheat-bulb fly.

(*a*) *Box experiments on insecticidal control*

The search for new materials to control wheat-bulb fly was extended to include fifteen more insecticides (barium silicofluoride, calcium arsenate, chlordane, fluoracetanilide, lead arsenate, "Lethane", malathion, mercurous chloride, methoxychlor, paraoxon, "Pyrolan", sodium fluoracetate, "Thimet", toxaphene, zinc fluorarsenate). These were formulated as seed dressings and compared with seed dressings of dieldrin and heptachlor. The technique used for assessing the protection afforded by a dressing against wheat-bulb-fly attack has been described in previous annual reports. As in 1956, no insecticide was significantly better than dieldrin or heptachlor, but chlordane, which contains some heptachlor, was comparable.

A paper on seed dressings for wheat-bulb-fly control has been submitted for publication. The work is continuing.

(*b*) *Field experiments on insecticidal control*

(1) *Pennells Piece.* The experiment on Pennells Piece was continued. Various formulations of aldrin and dieldrin were tested, the materials being applied either as dusts on the soil surface or combine-drilled with the seed. Unfortunately the numbers of larvae present were very small, only 7 per cent of the tillers being damaged on the untreated plots. Nearly all the measurements made, including yields of grain, failed to show any significant differences, but Table 2 and other results are consistent in indicating that 4 per cent dieldrin dust at 1 cwt./acre broadcast on the soil surface in December gives control equal to or better than a similar quantity of dieldrin combine-drilled with the seed.

TABLE 2

Effect of soil insecticides on wheat-bulb-fly damage

Treatment	* Damaged Tillers (in thousands per acre) on 14 April 1957	† Yield at harvest in cwt./acre (85% dry matter)
Untreated	17·3	50·0
4% dieldrin dust broadcast at 1 cwt./acre 18 December 1956	1·8	54·8
4% dieldrin dust broadcast at 1 cwt./acre 16 February 1957	5·0	50·2
4% dieldrin dust combine-drilled with seed 5 November 1956 at 1 cwt./acre ...	6·8	52·1
1·5% dieldrin dust combine-drilled with seed 5 November 1956 at 1 cwt./acre ...	7·5	54·1
1·5% aldrin dust combine-drilled with seed 5 November 1956 at 1 cwt./acre ...	6·3	51·9
1·2% dieldrin granules combine-drilled with seed 5 November 1956 at 1·5 cwt./acre...	8·8	50·0

* Least significant difference between means (5% level) = 6·9.
† No significant difference.

(2) *Broadbalk Sideland.* Though parathion sprays have been moderately successful at Rothamsted, other workers using differing formulations have found this method of control very unsatisfactory. In an experiment on Broadbalk sideland, seven different spray treatments were compared.

A standard parathion formulation was applied to separate sets of plots on three different dates. On one of these dates a formulation containing " Thimet " and three other parathion formulations were also applied to other plots.

The percentage of attacked tillers was rather higher than in the Pennells Piece experiment, the unsprayed plots having up to 22 per cent attacked tillers, but only two measurements of samples showed any significant differences. Yields were not taken.

Table 3 shows that the only treatments which showed a significant reduction in the numbers of living larvae compared with the untreated plots were the standard parathion spray applied on the earliest date and two other parathion formulations, one of which contained a high percentage of wetter and another which contained a sticker to give better leaf-adhesion. The latter also had a significantly larger number of undamaged tillers than the untreated plots.

Wheat leaves are very difficult to wet, and it is probable that the effect of these two formulations was to increase the parathion deposit on the leaves, by better wetting or greater adhesion. The formulation with a high proportion of wetter was used in the previous year's experiments on Pennells Piece.

TABLE 3

Control of wheat-bulb fly by organophosphorus sprays

Treatment	Undamaged tillers (17 April 1957)	Increase	Live larvae per sample (square root transformation) 28 March 1957	Decrease
Unsprayed	1254·3	—	4·0	—
0·1% "Thimet" (w/v) applied as 0·24% emulsion of liquid containing 47·5% Thimet (sprayed 15 March 1957) ...	1284·2	+ 29·9	3·3	0·7
0·1% parathion + 0·18% xylene + 0·4% wetter (sprayed 27 February 1957)...	1305·7	+ 51·4	3·0	1·0
Ditto, sprayed 15 March 1957...	1064·8	−189·5	3·4	0·4
Ditto, sprayed 12 April 1957 ...	1606·5	+352·2	—	—
0·1% parathion + 0·26% xylene + 0·014% wetter (sprayed 15 March 1957) ...	1030·2	−224·1	3·5	0·5
0·1% parathion + 0·4% wetter (sprayed 15 March 1957) ...	1740·0	+485·7	2·8	1·2
0·1% parathion + 0·183% xylene + 0·014% wetter + 0·6% methyl cellulose ether (sprayed 15 March 1957) ...	1751·3	+497·0	2·5	1·5

All parathion measurements are by volume. The wetter used was Atlox 3335 (Honeywill Atlas Co. Ltd.).

Least significant difference of means (at 5% level) = 493·6.

Least significant difference of means of untreated and any treatment (at 5% level) = 1·0.

Bean aphid Aphis fabae *Scop.*

Work on the biological, ecological and chemical factors concerned in the infestation and control of *Aphis fabae* Scop. has been carried out by M. J. Way assisted by T. Doherty.

Chemical control of Aphis fabae *Scop. on spring-sown field beans by low- and medium-volume sprays*

In a field trial a comparison was made of five insecticides each applied once (on 13 June) at a fixed rate of active ingredient in 60 gallons (medium volume) and in 10 gallons of water/acre (low volume). Analyses showed that more insecticide was retained on the plant by the low-volume application. Table 4 gives details of aphid populations and crop yields for the different treatments. It can be seen that the efficiency of *A. fabae* control was not affected by the volume sprayed except with malathion, which did significantly better at the medium volume. The systemic insecticide

treatments stopped the aphid numbers from rising above a maximum of 8 per plant compared with 3,550 per plant for check treatments sprayed with wetter only. The single spraying by a systemic insecticide raised the crop yields from around 4 to 27 cwt./acre.

TABLE 4

Aphid counts and grain yields on plots treated with insecticides at medium and low volumes

Insecticide	Wt. of action ingredient, oz./acre	Peak aphid, numbers/stem		Yield, cwt./per acre	
		Medium volume	Low volume	Medium volume	Low volume
Lindane	6	2,817	2,398	4·9	8·0
Malathion	12	119	233	19·3	16·0
Demeton-methyl ...	6	4	3	27·3	26·3
Compound 4741 ...	3	8	5	28·1	27·4
Fluoroacetamide ...	3	1	1	26·7	26·8
Check	—	3,466	3,547	5·3	3·3

Effect of planting date on infestation and control of Aphis fabae *Scop.*

This year's field trial completed the work on this problem. Field beans were planted at three different dates, and for each planting date yields of unsprayed plots were compared with those of plots sprayed once and twice with demeton-methyl (" Metasystox ") at 6 oz. of active ingredient/acre.

It was interesting that the type of aphid population which developed was at the opposite extreme to that of 1955. In 1955 there was a small primary migration in June and numbers on the crop rose to a peak in August; early sown plots were little affected,

TABLE 5

Effect of chemical control of A. fabae *on field beans sown at different dates*

Time of spraying	Peak aphid numbers per stem for different sowing dates			Grain yields for different sowing dates, cwt./acre		
	20 March	30 April	15 May	20 March	30 April	15 May
Untreated	6918·0	575	38·0	0	9·4	12·3
13 June	3	47	40	16·7	15·3	13·8
13 June and 5 July	—	—	—	18·0	16·9	13·5

but untreated late-sown ones were severely damaged. In 1957 there was a big migration in early June, and numbers on the crop rose to a peak in late June and early July. Table 5 shows that unsprayed early sown plots were devastated by *A. fabae* but late-sown plots were little harmed. A single early application of aphicide stopped damage on early sown plots, but was relatively less effective on late-sown ones. Peak numbers were reached on all plots before 5 July; the second spray treatment was therefore applied to a declining population, and it is surprising that it significantly increased the grain yield of plots sown in March and April.

Natural control in relation to chemical control of Aphis fabae *Scop.*

This work was continued in collaboration with C. J. Banks of the Entomology Department.

Overwintering eggs of *A. fabae* began hatching in mid-February compared with late March in 1956; the warm winter was seemingly responsible. Continuing favourable conditions caused the primary migration from *Euonymus europeus* to the crop host to begin as early as mid-May.

As expected (see *Rep. Rothamst. exp. Sta. for* **1956**, 144), big populations of aphids developed on spring-sown beans in the Harpenden area during June. This was followed by a sharp fall in numbers in early July. Numbers remained low until late August, when populations developed on wild hosts, notably *Chenopodium album.* Many aphids returned to *Euonymus* in September and October, and more eggs were laid than in 1956. It is expected therefore that in the Harpenden area spring-bean crops will be damaged severely by *A. fabae* unless control measures are adopted.

Studies on natural and on artificially established populations of the aphid and its natural enemies were continued on *Euonymus*, beans, sugar beet and *Chenopodium*, using the caging method as in 1956. Sticky traps were also used to estimate the activity and abundance of flying predators throughout the year. The results have not yet been examined in detail; predators were especially abundant from mid-June to July, and the cage experiments showed that they were important in keeping the aphid numbers at a low level during July. This was confirmed by experiments in which attempts were made to keep plots free of predators by hand picking.

In 1957 natural enemies had become abundant and the general aphid population had begun to fall before aphids became well established on their crop hosts. Adult predators attacking the newly established colonies were probably responsible for *A. fabae* populations not developing to damaging numbers on some bean and sugar-beet crops in Eastern England. There was no evidence, however, that where insecticides were used they upset the natural control.

The distribution of high- and low-volume sprays on field beans

As an adjunct to experiments on the control of *Aphis fabae* Scop., some data were collected by R. Bardner on the distribution of spray deposits on field beans, using a colorimetric method for estimating deposits of a water-soluble dye included in the spray mixture. The method is due to Hebblethwaite (1956: *Plant Path.* **2** (3), 93), who used it for examination of spray deposits on potato foliage.

Estimates were made of deposits in the " crown " of the bean plant (unopened leaves and flower bracts) as compared with the rest of the plant (stem and opened leaves) for sprays applied at 10 and 60 gallons/acre. A very-late-sown bean crop was used, which at the time of the experiment was only 10–12 inches high. The plants possessed a well-developed crown, and apart from the length of stem were in a similar stage of growth at the time of spraying to plants in other spraying experiments.

Two spray mixtures were used: (*a*) high volume, containing 2

per cent Nigrosine 865 (by weight) and 0·5 per cent benzoyl-*p*-oxydiphenyl-polyglycol ether (by volume) as wetter; (*b*) low volume, containing 1 per cent Nigrosine and 0·125 per cent benzoyl-*p*-oxydiphenyl-polyglycol ether.

The sprays were applied with the department's tractor-mounted sprayer, with jets mounted vertically above each row of plants. Jets were arranged 2–3 inches above the crop for the low-volume application, and 10 inches above the crop for the high-volume spraying.

Immediately after the spray deposit had dried, a sample of thirteen plants was cut at ground level and removed from each treatment. The Nigrosine deposit was washed off and estimated colorimetrically at 580 μV. The colorimeter was calibrated with serial dilutions of a Nigrosine solution of known strength. Results were expressed as the equivalent of ml. of low volume spray mixtures retained by each plant, it being assumed that 1 ml. of low-volume insecticide mixture would be equivalent to 6 ml. high-volume mixture. Variance analysis showed that highly significant differences existed (Table 6).

TABLE 6

Retention of equivalent spray deposits on plants

Low volume		High volume	
Crown	Rest of plant	Crown	Rest of plant
2·42	46·73	1·66	14·50

Least significant difference between means (5% level) = 6·05.
Least significant difference between means (1% level) = 8·06.

Differences in deposit between the crowns of the plants were not significant. This was so even when deposits on the crowns were analysed separately. The plants sprayed at low volume had much higher total deposits than those sprayed at high volume. It is probable that in the high-volume treatment droplets would coalesce and drip off the leaves before drying.

Evidence for this was provided by an additional experiment, Nigrosine was replaced by Primuline A150, a dye which fluoresces in ultra-violet light. The technique has been described by R. B. Sharp (*N.I.A.E. Tech. Memor.* 119, 1955). Examination of photographs of sprayed leaves showed that with low-volume application the droplets remained discrete on the surface of the plant. With high-volume sprays the droplets coalesced, and the deposit was heaviest along the lamina of the leaves, indicating that run-off had occurred. Deposits in the crown of the plant are the most important for aphid control in the early stages of attack, and in this connection it is of interest that not only were these crown deposits very similar for either method of spraying, but that the degree of aphid control achieved in the experiment on Deacon's field (described elsewhere in this report) in 1957 was very similar for both high and low volume for most insecticides.

This work is being continued.

Mode of action of seed dressings

M. J. Way has carried out a series of laboratory and pot experiments and confirmed the systemic action of dieldrin used as a seed

dressing against *L. coarctata*. It was shown that systemic action may be solely responsible for killing the larvae when the treated wheat seed is sown deeper than about 1½ inches with the *L. coarctata* eggs less than about 1 inch deep in the soil. Contact action may be important with a shallow-drilled crop and also if the eggs lie below the level of the treated seed. These conclusions were substantiated by a preliminary experiment with treated seed sown at different depths which showed that seed dressings were more effective with the shallow-drilled crop.

Dieldrin seed dressings can apparently stop damage to young onion plants by larvae of the onion fly *Hylemyia antiqua*, which is closely related to *L. coarctata*. Observations were begun on *H. antique* which may, perhaps, lead to an explanation of the comparative ineffectiveness of dieldrin against *L. coarctata*.

The control of the vectors of potato virus diseases

P. E. Burt continued to work in collaboration with L. Broadbent of the Plant Pathology Department on this subject. The joint work is described in the report of the Plant Pathology Department.

Fungicides

Only a small amount of work on fungicides was done in 1957, first, because F. T. Last was away on secondment in the Sudan, and secondly, because A. H. McIntosh had to spend a great deal of time helping and supervising M. Das in his work on the effect of temperature on the toxicity of insecticides.

The work described below was carried out by A. H. McIntosh.

Technique for spore-germination tests

A method has been worked out for making cavity-slides from perspex. The cavities are made by "shock-moulding" perspex sheet, ¼ inch thick. The cavities are cylindrical and of uniform size (1·41 cm. diameter × 1·25 mm. deep); their surface is flat and transparent. No drilling, polishing or cementing is needed. The slides are cheap and easy to make, and are almost unbreakable. They have the disadvantage that they will not withstand washing in strong acids, and in some organic solvents.

These perspex slides are now being used in our spore-germination tests of water-soluble fungicides. They are used in the same way as Böttcher's slides, as described in *Rep. Rothamst. exp. Sta. for* **1956**. They are cleaned by swabbing with cotton-wool and washing in running water, and can be dried at 70° C. without deformation.

Time, temperature and toxicity of fungicides

The work reported last year has been continued, using spores of a strain of *Botrytis fabae*, in slide-germination tests.

Interest has centred on salts of mercury, all of which gave positive temperature coefficients of fungitoxicity. When counts were made 48 hours from the start of the experiment, the temperature coefficients between 10° and 25° C. were: $Hg(CN)_2$, 17; $HgCl_2$, 7·1; $HgBr_2$, 2·8; $Hg(CNS)_2$, 3·4; HgO, 2·5; $Hg(OAc)_2$, 1·9. However, after an interval of some months, we found that the culture of our

strain of *B. fabae*, although still pathogenic and still growing and sporing well, had changed in an unexpected way: the temperature coefficients are now very much smaller than before. For example, the temperature coefficient of $HgCl_2$ is now only 1·4; the susceptibility at 25° C. has remained almost unchanged, but the susceptibility at 10° C. has increased sharply. The reason for this change is not known. The work on mercury salts is now being extended to other species, and if possible to other strains of *B. fabae*.

The adsorption of mercury from solution on glass and perspex surfaces is a possible source of interference in spore-germination tests, in which very dilute solutions are used. We have found that the loss in strength of solutions of $HgCl_2$ (0·0005 per cent Hg), kept in small perspex pots, is about 6 per cent in 24 hours. This loss is not affected by temperature in the range 10–25° C. The loss on soda-glass tubes is almost identical, and is not affected by temperature.

ENTOMOLOGY DEPARTMENT

K. Mellanby

General

Barbara M. Stokes (now Mrs. J. Hirst), Lois M. Cherry, J. C. da Silva Dias, D. L. Milne and M. A. Zaher left, and Margaret K. Arnold, Jane A. Cochrane (Robert Donaldson Scholar, University of Glasgow), Joan Riches (Agricultural Research Council Scholar) and B. Gerard joined the department. C. G. Johnson was absent from Rothamsted for the whole year during his period of secondment to the West African Cocoa Research Institute in Ghana.

K. Mellanby attended the first meeting as a member of the editorial board of the new journal *Entomologia Experimentalis et Applicata* in Amsterdam in October. P. W. Murphy, who is a member of the Zoology Committee (Biology Commission) of the International Society of Soil Science, attended a meeting in Geneva to discuss the organization of the International Colloquium on Research Methods in Soil Zoology to be held at Rothamsted in July 1958. R. M. Dobson gave a course on "Animal Life in the Soil" at Flatford Mill (Field Studies Council) in August. Many papers were read by members of the department at conferences and meetings of scientific societies, for example, R. M. Dobson, D. B. Long, Barbara Stokes and F. Raw each made a substantial contribution to the Symposium on the wheat-bulb fly held by the Association of Applied Biologists in January.

The University of London awarded the degree of Ph.D. to M. A. Zaher and D. L. Milne, and that of M.Sc. to Lois Cherry.

The constant-environment rooms in the West Building have at last been completed, and are providing much-needed facilities for experimental work, but the problems caused by the noise made by the machinery for the rooms in the Entomology Department (where no cellars are available to house motors and compressors) have not yet been solved. The glasshouses and insectaries are still being erected; the official date for their completion was December 1957, and we hope to occupy them sometime in 1958.

Insects and Climate

Effects of climatic factors on metabolism and behaviour (K. Mellanby and R. A. French)

Observations have continued on the plots on Bones Close and Furzefield (selected as likely to have different microclimates), where cabbage white caterpillars have been studied on brussels sprouts. Unfortunately the plot on Furzefield is adjacent to Knott Wood, and birds from the wood have consumed so many of the experimental insects that few results have been obtained. However, the extent to which birds may control caterpillars has been studied. A "hide" was erected, and the plot was kept under observation

for several periods from before sunrise to after sunset. The most important period of bird activity was from 10 minutes before sunrise to 20 minutes after; different species of birds entered the crop at different, and fairly regular, times. The plot on Bones Close is farther (about 300 yards) from any wood, and here very few caterpillars were ever eaten by birds.

In the laboratory, work has continued on effects of temperature and humidity. Many larval insects have been found to drink water in considerable quantities. They store this water in their tissues, and can then survive exposure to unfavourable temperatures. Even plant-eating larvae, which are usually believed to obtain ample supplies of water with their food, have been found to drink water when they are somewhat dehydrated, which happens if they feed on partially wilted leaves. Several species of soil-inhabiting larvae, including some of agricultural importance (e.g., the frit fly), seem often to drink water. A paper on " The importance of drinking water to larval insects " was read to the Conference of the Society for Experimental Biology in London in December.

Experiments have been continued on activity and survival at low temperatures. It has been confirmed that acclimatization may occur very rapidly (partially within 3 hours, completely within 24 hours) and that although this is as rapidly reversed at temperatures where activity is possible, at 0° C. (where chill coma occurs in many species) insects briefly acclimatized beforehand may retain this quality for many weeks. The significance of this in relation to the winter survival by pest insects is being studied.

Fat metabolism and temperature (Lois M. Cherry, R. A. French and K. Mellanby)

Work has continued on the analysis of fat from insects reared at, or acclimatized to, different temperatures, and also on the effects of differences in diets on the composition of the fat reserves. Although it was found possible to obtain fat reserves with very different properties in one species of insect, and although similar conditions of diet and temperature during growth gave repeatable results, the nature of the fat seemed to have little direct relation to the ability of the insects to withstand high temperatures.

Insect Pests at Rothamsted and Woburn

(R. A. French and K. Mellanby)

The only really important damage caused by insects in 1957 appeared to be that due to aphids, particularly *Aphis fabae*. These arrived on the crops in great numbers in early spring, and only the earliest planted beans had developed sufficiently to give a crop after the aphid attack developed. However, during spring and early summer parasites and predators increased also, and achieved some measure of control.

The Bean weevil *Sitona lineata* was very common on beans which were grown on fields which bore the same crop in the previous year, but the comparatively heavy infestation (the edges of almost all the leaves of the young plants were " scalloped ") did not seem to

reduce the yield, but other factors (e.g., aphids) complicated the picture. More work on this species is urgently needed.

Most other common pests have been found in small numbers, insufficient to be likely to cause serious damage to crops.

Frit Fly Investigation

(Joan Riches and K. Mellanby)

Work on the biology and ecology of the frit fly has begun with a survey of infestation on parts of Rothamsted farm, and with experiments on development and survival in the laboratory.

Gall Midges of Economic Importance

(H. F. Barnes, Barbara M. Stokes, D. L. Milne and Margaret K. Arnold)

The long-term study concerning the two wheat blossom midges, having passed its thirtieth successive year, was modified so as to allow the descent of the larvae from the ears on Broadbalk to be compared with their descent on other fields on the Rothamsted Farm and elsewhere. The main features of the study have, of course, been retained. Thanks to the co-operation of Professor M. McG. Cooper and Mr. A. D. Rivett, samples of Square Heads Master (the variety sown on Broadbalk) were received from Cockle Park, Durham, for the first year in this proposed 5-year study of the phenology of the wheat-blossom midges on autumn-sown wheat in two widely separated areas. On Broadbalk the larval descent occurred 9–12 July, whereas at Cockle Park it apparently took place about 22–25 July. However, on spring-sown wheat (Koga II) on Harwoods Piece there were still plenty of *C. tritici* larvae up in the ears on 25 July. It had been noticed previously that oviposition did not start on Harwoods Piece until it had practically finished on Broadbalk and that the ears of wheat were correspondingly later in appearing in this field of spring-sown wheat. As regards the infestation of Broadbalk, 1957 was, as expected, a trough year, there being only 4,596 *C. tritici* and 602 *S. mosellana* per 500 ears, representing a 4·2 and 2·1 percentage grain infestation respectively.

A further advance has been made in the biological testing of sorghum midge from tropical countries. Some years ago midges were reared from the Gambia. This year midges were reared from Ghana in West Africa and from Mysore State in India. Experiments showed that inter-mating would take place between midges from these two continents, but no evidence was obtained concerning the fertility, as no sorghum plants were in the right stage of growth at the time of the midges' emergence. It is hoped to make another start in the investigation when the new heated glasshouses are available.

It has been demonstrated from inter-breeding experiments between Hessian Fly from Kansas, U.S.A., northern Germany and Harpenden, involving just over 10,000 emergences, that they will inter-breed successfully up to and including the fourth generation. First crosses, back crossings and selfing of crosses all resulted in

fertile offspring. There is now no reason to doubt, taking into consideration the range of variation in morphological characters and this establishment of the fact that Hessian Fly from the two continents will inter-breed, that the true Hessian Fly, *Mayetiola destructor* (Say), does occur in Europe.

The maintenance of stocks of Hessian Fly on wheat, barley, rye and couch grass preparatory to testing the possible development of host-plant races has been discontinued. It is hoped, however, to continue testing the validity of the described species of *Mayetiola*.

Observations and breeding experiments have shown that the *Stenodiplosis* found ovipositing on timothy grass inflorescences in 1956 is none other than the well-known *S. geniculati* Reuter of foxtail grass. This midge was studied about 1929 on foxtail grass and discovered in 1938–39 to be also breeding on cocksfoot grass in various parts of England and Ireland. The second flight of the year, derived from the first generation on foxtail, emerges at Harpenden too late to re-infest foxtail, but just at the right time to attack timothy grass inflorescences. An investigation has been started to determine how widespread is this breeding on timothy grass.

The life history study of the new *Contarinia* species of timothy grass inflorescences, received originally from Finland, although previously known from larvae to exist in England, has shown that there is but one generation a year.

The investigation of the gall-midge fauna of clover flower heads has been brought to a conclusion, the results being incorporated in the thesis presented to London University by D. L. Milne. Four new species, one of which does primary damage to seed formation, have been described. They belong to the genera *Tricholaba*, *Clinodiplosis*, *Giardomyia* and *Isodiplosis*.

Stocks of pea midge (*C. pisi*) larvae have been accumulated preparatory to studying the phenology of this injurious species.

The collection of gall midges (now containing upwards of 13,000 slides), as well as the card indexes, has been considerably increased, although there is an increasing back-lag in the identification and taxonomic service which H. F. Barnes provides.

Some idea of the extent of the advisory and consultant work that is carried on can be gauged from the fact that in the first 3 months of the year just over a hundred letters dealing with gall midges were received from twenty-two different countries. Mr. K. M. Harris, on leave from Nigeria, spent 2 weeks studying gall midge, particularly the new sorghum stem midge.

Studies on Slugs

(Jane A. Cochrane and H. F. Barnes)

Three species of slug, *Milax budapestensis*, *Agriolimax reticulatus* and *Arion hortensis*, are being collected weekly from a garden in Harpenden. Records of weight, numbers and stage in sexual development (determined by dissection) are being kept in order to elucidate more fully the life cycle of these species. An existing slug ovicide is being tested on the eggs of all available slug species. Preparations are being made to start a programme of work shortly, whereby slugs will be marked with radio-active iodine in an attempt

to estimate total populations. The absence of a method of estimating populations has for many years hampered the testing of slug poisons in the field.

Wheat-bulb-fly Studies

Alternative host-plant studies (Barbara M. Stokes and F. Raw)

Observations were made on a natural infestation of alternative host plants on Bones Close fallow in spring 1957. This fallow plot, 400 yards away from a known source of wheat-bulb flies, was found to have an infestation of about 11 eggs/sq. ft. just prior to hatching. Grasses and weeds germinated on the fallow during the mild winter, and by spring the plant density gave about 100 shoots/sq. ft. In early April all the plants from eighteen quadrats 1 foot square were examined for wheat-bulb-fly larvae or symptoms of damage. Only three larvae were found, two in volunteer wheat plants and one in *Dactylis glomerata*. Five shoots of *Poa annua*, three of wheat, two of *Agropyron repens* and one of *Dactylis glomerata* showed damage characteristic of wheat-bulb fly.

This low infestation supports the results of some laboratory experiments on host-plant preferences which suggest that some alternative host plants are less readily infested than winter wheat. In pot experiments the percentage infestation of alternative host plants relative to wheat was:

Agropyron repens	Barley	*Agrostis tenuis*	Rye	*Festuca pratensis*	*Poa pratensis*
133	83	57	26	23	18

Field studies (F. Raw and J. R. Lofty)

The experiment on Broadbalk carried out previously in 1954–55, to estimate the effect of infestation on yield by screening strips of plots to prevent oviposition, was repeated. On the fallow section of plots 2, 3, 5, 7 and 10 two strips each 6 feet wide and running the width of the plots were screened with mosquito netting during the oviposition period in 1956. Counts in spring 1957 showed that 3 per cent of the plants in the previously screened strips were infested compared with 25 per cent in similar unscreened strips. At harvest no significant differences in yield between screened and unscreened strips was detected.

Previous work has shown that soil conditions greatly affect wheat-bulb-fly oviposition. In a factorial experiment on fallow at Rothamsted (*Rep. Rothamst. exp. Sta. for* **1954**) more eggs were laid in a rough tilth than a smooth tilth and more in plots which were cultivated during the oviposition period than in undisturbed plots. It has also been shown that the different levels of infestation established in this way may be used to investigate the effect of infestation on yield (*Rep. Rothamst. exp. Sta. for* **1955**). There is some circumstantial evidence from plant counts that the survival of wheat-bulb-fly larvae on hatching may be affected by the numbers of wheat shoots available for infestation even when there are more shoots than larvae. To obtain further data on these aspects of the wheat-bulb-fly problem two field experiments have been started on farms in Essex where heavy infestations frequently occur.

In each experiment four treatments in five randomized blocks of four plots each were applied to fallow during the oviposition period. They were:

(1) rough tilth cultivated at 7–10-day intervals;
(2) undisturbed rough tilth;
(3) undisturbed smooth tilth;
(4) screening with mosquito netting to prevent oviposition.

In early October each experiment was drilled with Cappelle wheat at two seed rates on split plots to give contrasted shoot densities in spring. At one site the seed rates were 3 bushels/acre and 1 bushel/acre, at the other 3 bushels/acre and $\frac{2}{3}$ bushel/acre.

The response to the fallow treatments has been estimated by taking twenty soil samples each $2\frac{1}{2}$ inches diameter and 8 inches deep from each plot and extracting the wheat-bulb-fly eggs by a standard flotation method. The results show a striking response to the different tilths.

Numbers of wheat-bulb-fly eggs (thousands per acre)

Tilth	Herkstead Hall	Fowes Farm
Rough cultivated	1,400	3,000
Rough undisturbed	650	1,400
Smooth undisturbed	150	500

Estimates of plant infestation and larval survival will be made in spring, and plot yields will be recorded at harvest.

Field studies on emergence, survival and activity (R. M. Dobson)

The Pennells Piece cage experiment was repeated with considerable improvements in technique. This experiment involves carrying out a marking and recapture experiment on a small population which is prevented from dispersing by being confined within a cage of mosquito netting (dimensions 24 × 12 × 6 feet). In the 1956 experiment the cage was erected in an infested wheat field, and all the flies which emerged inside it were marked according to their date of emergence and were then released. They were subsequently recaptured and re-released at 3-day intervals. From the data obtained, information on emergence and longevity could be derived. In the 1957 experiment the flies emerging inside the cage were considerably augmented by introducing flies derived from pupae collected on Broadbalk, and for marking, special nitrocellulose paints (kindly provided by Imperial Chemical Industries Ltd.) were used. These paints proved superior to the oil paints used previously. Each fly was marked so that it could be distinguished individually by applying three spots of paint to the dorsum of the thorax in the form of a triangle. Seven different colours were used, so that 343 (i.e., 7^3) different combinations could be obtained. This proved adequate, but had more combinations been required it would only have been necessary to have altered the configuration of the spots. As flies were now recognizable individually, it was not necessary to touch them on " recapture " days, and hence any possible deleterious effects of handling were eliminated. This meant that " recapturing " could be carried out daily so that more precise data could be obtained.

Information on activity was derived from the daily records and also from continuous observations over 24-hourly periods. The data are now being analysed in co-operation with Marjorie G. Morris of the Statistics Department.

Larval studies (D. B. Long)

The spring survey of larval infestations in the first wheat crop after fallow showed some of the lowest levels since they were begun in 1954. The population on the alternate wheat and fallow plots had fallen from 583,000 in 1956 to 193,000 larvae/acre infesting 10·2 per cent of the plants, whilst on Broadbalk there was a decrease from 635,000 to 370,000 larvae/acre infesting 30·6 per cent of plants. In both years the larval infestation in wheat following a preceding wheat crop was slightly under 2 per cent of the infestation in the first crop after fallow.

The maximum population on Broadbalk coincided with the period of maximum tillering. Plant damage by wheat-bulb fly was not necessarily associated with increased tillering, and increased tillering did not result from experimental damage to shoots.

In the experiment set up on the alternate wheat and fallow using seed rates of $\frac{1}{3}$ and 3 bushels/acre, the larval population on the low-density plots was little more than one-half of that on the high-density plots, indicating a higher larval mortality on the former, although the surviving larvae were more advanced in their development. When compared with the high-density plots, the low-density plots had 77·3 per cent of their shoots damaged in contrast to 20·0 per cent, but carried 3·7 in contrast to 2·1 shoots per plant. At harvest the low-density plots carried one-third of the number of stems, but the ears contained three times the number of grains and yielded 9·1 cwt./acre in contrast to 10·3 cwt./acre.

Pot experiments on the mechanism of host-plant location by newly hatched larvae suggest that the larvae move upwards at a fairly steep angle from the egg site and then move horizontally in the surface layers of soil. Plant location did not appear to be assisted by the root extremities but to depend on attractant material exuded by the plant into the root zone close to its base and into the soil surrounding the stem. The results indicated that the attractive root zone may possibly interfere with successful infestation. Direct observation of larval movements in the laboratory confirmed the attractive function of the root and stem exudates and also showed the leaf-tip guttation droplets to be attractive. The exudates were found to contain a thermolabile component which was responsible for about one-half of their attractiveness. It had earlier been observed in the field that larvae tended to attack fresh plants in preference to those already infested. Laboratory experiments showed that this was due to the exudate being less attractive and not to the production of a repellent substance. The work is being continued.

Adult studies (D. B. Long)

In nutrition studies the female was found to survive longest on a diet of honey, old bee pollen and water; on this diet the largest number of eggs per female was also produced. Diets simulating

food conditions within wheat fields offering fresh wheat pollen, wheat washings and water were associated with the shortest survival times and a failure to mature eggs. The studies confirmed earlier findings suggested the probable importance of a source of food containing sugars for continued life and egg maturation. Such a source is not normally freely available in wheat fields, and suggests that the daily dispersion of flies from the crop earlier observed may be due to their foraging for food.

It had been observed that flies brought into the laboratory were frequently parasitized by fungus, and this was responsible for 50 per cent of deaths of females used for breeding in 1956, of which 35 per cent was caused by an entomogenous fungi which had been recorded only once previously in another Anthomyid fly. This fungus characteristically caused the formation of a hollow cyst in the abdomen which eventually opened to the exterior through the ventral surface of the abdomen a day or two before death occurred. Particular attention was given to this fungus and two others which destroyed the abdominal contents.

In collaboration with E. W. Buxton (Plant Pathology Department), several fungi were isolated and cultured; inoculation tests were carried out on 2,630 flies freshly caught in the field, of which 1,670 were female. The tests were carried out in the laboratory using glass breeding jars and outside in the open air in terylene cages. A further account of this work, which is being continued, is given by E. W. Buxton.

Aphid Ecology and Insect Dispersal

Dispersal and meteorology (C. G. Johnson)

The material obtained in previous years' trapping is gradually being sorted and analysed. The essential nature of wind-directed and assisted dispersal in aphids is already apparent. The meteorological conditions associated with dispersal at different levels have been dealt with in a preliminary analysis using the earlier trap catches, and a definite association between height of dispersal and a measure of atmospheric instability was shown to exist.

Dispersal and periodicity (L. R. Taylor)

The general pattern of dispersal in aphids, as it appears from the study of flight periodicity by trapping, was compared with the conclusions drawn from the observational work done on locust dispersal in a talk given before the Linnean Society. It appears that, in spite of the great difference in size and flight power of the insects, and the consequent difference in the methods used for their study, the dispersal processes could be fundamentally the same.

Some of the problems involved in this type of dispersal are common to all sizes of insects and also to plant spores, particularly those associated with crossing the layer of relatively still air near the ground before free circulation can be entered.

The establishment and growth of aphid populations (L. R. Taylor and A. J. Cockbain)

Aphid dispersal can be regarded as having three main stages which require separate investigation. The processes involved in

take-off and getting airborne have been largely dealt with and the work published. The second stage of aerial dispersal has been tackled mainly by trapping, and is discussed above. The final stages are alighting and the establishing and growth of a new colony. Although the analysis of the middle stage is not yet completed, the exceptionally large spring migration gave a good opportunity to begin field investigations on the third stage. Large numbers of aphids are essential for this, because the losses during migration must be of a very high order. Work has therefore been started on several aspects of this stage of aphid dispersal.

Aphids' migratory behaviour leads to wide dispersal and produces a very large element of chance in host finding. Also behaviour relating to secondary take-off is complex and field records are limited. A quantitative study of the alighting and taking off again of aphids on various host and non-host plants has therefore been started.

Analysis of the initial stages of growth of *Aphis fabae* populations on beans and other hosts suggests that the attractiveness of the host may be judged in terms of the resulting population structure. The growth pattern of field populations is also being analysed. The length of the four instars is very similar, and by using this period as a time unit a provisional study of reproductive rates is being made independent of growth rates. Rate of growth will be re-introduced later when the temperature relationships of growth and reproductive rates have been elucidated.

Population-growth curves in the field must eventually be related to time and therefore to temperature. This is being investigated for *A. fabae* in the laboratory, but, as little is known about the limits of reproductive capacity of alienicolae, this is first being investigated at 20° C. in apterae and also in alatae. With alatae the problem of the effect of flight on reproduction must also be dealt with.

An investigation of the morphological characters associated with the several nymphal stages of *A. fabae* and with the phases of adult life has been almost completed. This is necessary to ensure accurate analysis of field populations. There is a considerable overlap of size in the four instars and segregation on this basis was found to be unsatisfactory. The characters chosen must be easily visible under the low-power binocular for dealing with large colonies and, of the several features investigated, cornicle length is probably the safest and easiest to use in practice. A curious feature of the apterous alienicolae is the long post-reproductive phase in which size, lost during reproduction, is regained before a final collapse.

Effect of planting date on the growth of aphid populations (L. R. Taylor, A. J. Cockbain and K. Mellanby)

An experimental plot of field and broad beans, with randomized, replicated rows, sown fortnightly from January to May, produced a crop with every stage of plant growth from seedling to full flower during the primary aphid migration.

Inspection several times during the migration showed that the relationship between the number of primary migrants found on a plant and plant age and distribution was not simple; it varied

more between the inspection on different dates than between different treatments at the same inspection. Subsequent colony growth was followed on each plant in one row of each treatment, but a better understanding of the way in which colonies develop is required before full use can be made of this information.

Yield was measured and as expected was low, for the infestations were heavy (100 per cent plants infested), and in addition there was a high incidence of several virus diseases. One interesting feature was the control, by parasites and predators, probably bred on the earlier infestations, of the aphid populations on the last sown rows. These bean plants had not appeared during the primary migration and were only infested when the apterae from the nearby earlier sown rows began to spread. The aphid populations were, as a result, later, and were controlled naturally before they killed the plant. Regeneration was possible, but too late to save the flower, and the yield was small and failed to ripen.

Temperature and moulting (J. C. da Silva Dias)

The effect of temperature on the time taken for an alate aphid (*A. fabae*) to escape from the skin of the last nymphal instar was investigated. This act is performed successfully at temperatures down to 2·5° C. Above about 34° C. the resulting alates are usually subnormal and above 35° C. death usually ensues. The curve relating rate to temperature has the nature of an activity rather than a developmental process. It remains now to see how the physiological processes preceding this act in ecdysis respond to the same temperature range.

Earthworm Studies

Rehabilitation of marginal grassland (F. Raw and R. M. Dobson in conjunction with E. Crompton of Durham University)

Observations are continuing on the field experiments at Lancaster laid down in 1954 to investigate the influence of earthworms on the rehabilitation of marginal grassland. The experiment at Rivington has been discontinued.

At Lancaster the grass on all the plots was burned in spring 1957 because analysis showed that residues of arsenic in the herbage on plots treated with lead arsenate in autumn 1955 were still too high to permit grazing. Afterwards the second dressing of phosphate, artificial fertilizers and farmyard manure was applied to the appropriate plots. Subsequent tests showed that the plots could be safely grazed, and since summer they have been well grazed by cattle and horses.

Differences in plant growth and soil characteristics associated with the fertilizer treatments are becoming apparent, and samples taken in spring 1957 also showed differences in earthworm populations associated with the treatments. In particular, the population of the plots which received lime and phosphate now greatly exceeds that of untreated plots. So far eight species of worms are known to occur on the plots.

Samples were taken in autumn 1957 to estimate numbers of earthworms and smaller samples were taken to estimate numbers of

cocoons. The examination of this material was still in progress at the end of December 1957.

Earthworm populations in orchards (F. Raw and J. W. Stephenson)

The effect of repeated applications of fungicides and insecticides on the earthworm population of orchards and the rate of removal of surface litter is being investigated in four orchards near Wisbech, where J. M. Hirst of the Plant Pathology Department is studying the epidemiology of apple scab.

These orchards were chosen because they have been found to differ in the rate at which apple leaves are removed from the soil surface during winter and because they receive different manurial treatments and varying amounts of fungicide. An estimate of the earthworm populations made in autumn by the permanganate sampling method is summarized below.

Orchard	Coleman	Garforth	Hudson	Ayers Orchard	Paddock
Manurial treatment	Compost up to 10 tons/acre	$(NH_4)SO_4$ 1 cwt./acre	Dung and straw alternating 10 tons/acre	Dried sewage sludge 3 tons/acre	None
Fungicide used	Captan and mercury preparations	Bordeaux low rate	Bordeaux medium rate	Bordeaux high rate	Drift from orchard
Earthworms, thousands/acre	520	480	300	1·4	80

Six species of earthworm were found in varying abundance in the different orchards. A pot experiment has been set up to investigate the rate at which these species take down apple leaves.

Biological studies (B. M. Gerard, F. Raw and K. Mellanby)

Experiments on earthworm biology and behaviour in the laboratory have been started. It is hoped to extend these to observations on microplots in the near future.

Effect of Insecticides on Soil Fauna

(R. M. Dobson)

Identification of the material taken from the field experiment at Haslemere (Plant Protection Ltd.) to investigate the long-term effects of BHC on the soil fauna is still in progress. It is hoped that this work will be completed in 1958.

Studies on Beetles

(R. M. Dobson)

Routine identification of *Carpophilus* spp. (Nitidulidae) has continued. In other respects this work has been held in abeyance during the current year.

Ecological Studies on the Natural Enemies of Aphids

(C. J. Banks)

Studies on the association of the Garden Ant, *Lasius niger*, with the Bean Aphid, *Aphis fabae*, and on the effects of the ant on the aphid's insect enemies, were continued in 1957.

When the aphids are attended by ants their excretion behaviour

alters and the normal dispersal of the apterae from the young apical growth of the bean plants is considerably delayed.

Experiments confirmed that *A. fabae*, when attended by *L. niger*, multiplies more than ant-free aphids on bean plants, in the absence of insect enemies. The average difference in numbers recorded was about one-third, the maximum being 70 per cent. No doubling or trebling of aphid numbers, as claimed by Herzig (1937), was ever recorded.

Herzig attributed the increased multiplication of ant-attended aphids to a direct stimulation by the ants of the aphid's excretion and feeding rates. Experiments were made in collaboration with H. L. Nixon of the Plant Pathology Department to test whether *A. fabae* on bean leaves excrete more when attended by *L. niger*. Young bean plants were put into water-culture solution containing P^{32} (300 μc./litre solution). Small groups of aphid nymphs feeding on the undersurface of a leaf became radioactive, and the honeydew excretion was taken from them by successive ants. The radioactivity of the ants was then compared with that of the honeydew discharged on to filter-paper by ant-free aphids on control plants. In twenty-eight experiments of this kind the attendance times varied from 19 to 158 minutes, the mean numbers of aphids were thirty-four (ant-attended) and thirty-two (ant-free), and the average number of ants was four.

The radioactivities of the aphids of the two groups did not differ significantly; but the activity of the honeydew collected by the ants was twice as much as that from the control aphids.

The "extra" radioactivity of the honeydew from the ant-attended aphids can be explained only by assuming that they absorbed more sap, thus supporting Herzig's hypothesis that the excretion and feeding rates of the aphid are stimulated by ant-attendance.

But no significant differences were found between the numbers of nymphs produced by individual ant-attended and ant-free aphids living on leaves of the same age; in contrast, the numbers were significantly affected by the age of the plant tissue on which the aphids were feeding.

It is suggested, therefore, that ant-attended aphid colonies multiply more because most of the aphids feed for a much longer time on young plant tissue, where they reproduce more, instead of moving on to older leaves, where they reproduce less. The aphid's reproduction rate is apparently not affected appreciably by the direct stimulation of feeding which results from ant-attendance.

Control of *Aphis Fabae* by its Natural Enemies

(C. J. Banks)

This work was continued in collaboration with M. J. Way of the Insecticides Department.

Overwintering eggs of *A. fabae* on spindle (*Euonymus europaeus*) began hatching in mid-February, instead of late March as in 1956. The warm winter and the continuing favourable conditions enabled the primary migration of the winged aphids to begin in early May.

As expected, large populations of aphids developed on spring-sown beans in June, but there was a sharp fall in numbers in early

July. Small populations continued on beans until late August, and at the same time colonies appeared on other host plants, notably *Chenopodium album*. Many aphids returned to spindle in September and October, and more eggs were laid there than in 1956. If the winter of 1957–58 should be mild, large aphid populations on beans in the summer of 1958 may be expected.

Studies of natural and artificial infestations of the bean aphid and of its natural enemies on *Euonymus*, beans, sugar beet and *Chenopodium* were resumed, using the caging method of 1956. Sticky traps were also used to estimate activity and abundance of aphids and predators during the year. Predators were especially abundant in early July, and the cage experiments showed that the predators were important in keeping aphid numbers low during July. This was confirmed by experiments in which attempts were made to keep plots free of predators by hand-picking.

Effects of Population Density on Insects

(D. B. Long and M. A. Zaher)

Experiments carried out on the effects of larval population density on adult *Plusia gamma* and *Pieris brassicae* have been continued. Although crowding which affects the larval colour produces various morphological differences in the resulting adult, the colour and wing pattern remain unaffected. The crowded adults not only live longer than their counterparts from solitary larvae but in the case of *P. gamma* consume less water as well as food.

A distinct relationship was found to exist between the relative lengths of the larval, pupal and preoviposition periods. In *P. gamma* crowded larval conditions which appreciably shorten the larval period resulted in a slightly longer pupal period, but were followed by a shorter preoviposition period than occurred in their solitary counterparts. In *P. brassicae*, however, crowding shortened both the larval and pupal periods but lengthened the preoviposition period. It is suggested that the relative duration of these growth stages reflected differences in the effect of crowding on the rates of somatic and gonadial development.

The crowded cultures of *P. brassicae* laid fewer eggs per female, and the egg clusters were generally smaller. Crowded *P. gamma*, on the other hand, laid more eggs, but as in *P. brassicae* these eggs had a lower mean weight, and the total weight of eggs laid was less than in the solitary cultures.

When the adults were crowded at low densities the effect on the longevity of the male was doubtful, but it was reduced in the female, and this may have been related to the reduction in the preoviposition time and the increased number of eggs laid.

Generally the effects of crowding in both larval and adult stages were most marked in the female.

Forest Soil Investigations

(P. W. Murphy)

A pilot experiment to test a technique for the determination of the rate of disappearance of beech litter from the forest floor has

proved successful. Leaves were marked with a spot of paint containing the isotope, Tantalum 182, and it was possible to recover them up to about 1 year after marking. Two further experiments were established during the autumn months of the present year. In the first leaves were marked *in situ*, and in the second, marked leaves from five beech woods with different humus forms have been placed under the same conditions, to find if there is any difference in rate of disappearance of leaves from different sites.

Leaf sampling indicated that rate of disappearance during the first 6 months was very slow indeed, but it is probable that there was a marked acceleration during the second 6 months. Weather conditions may play an important part, and for this reason it would be unwise to generalize at this stage.

Mr. D. S. Madge, an undergraduate student of Sheffield University, made a short laboratory study of the length of survival of certain species of oribatid mites in dry air, and at relative humidity levels of 25–40 per cent. Eight species associated with contrasting habitats were chosen for these experiments. In dry air the length of survival of the species studied varied greatly. At 10° C. *Nanhermannia nana* (Nic.) survived the shortest time, 50 per cent of the population dying in 1 hour. With *Oribatella quadricornuta* (Mich.) and *Belba* spp., 50 per cent of the population survived for periods of 48–60 and *c.* 66 hours respectively. At a temperature of 20° C. these times were usually very much shorter. On the whole, the results corroborated the evidence available concerning the environmental conditions of habitats favoured by these species. *N. nana*, for example, is normally associated with very wet places, such as sphagnum bog, and the evidence of this experiment indicates that it can only survive a short exposure to dry air. *O. quadricornuta*, on the other hand, is commonly associated with very dry places, such as stone walls, and it is therefore not surprising that it should survive exposure to a dry atmosphere for a very much longer time. It should be remembered, however, that the relative-humidity level within moss cushions on a wall may be quite frequently within the region of 70–80 per cent. The results for *Belba* are somewhat anomalous, as they are usually considered to be mesophyllous mites, and are found in leaf litter. Size of species and behavioural pattern appeared to have a marked effect on length of survival, and these may explain why the large *Belba* spp. survived for an unusually long time.

Laboratory studies of the biology of oribatid mites have been continued, and cultures of a number of species have been maintained. It has been found that *Fuscozetes fuscipes* (Koch) feed very readily on insect larvae. This is a rather surprising observation, as oribatid mites are generally considered to be detrital or fungal feeders. In collaboration with C. C. Doncaster of the Nematology Department, investigations of possible predators of nematodes and nematode cysts have been continued.

In April Dr. P. A. Ryke of the University of the Orange Free State, Bloemfontein, Union of South Africa, spent a short period at Rothamsted to gain experience of techniques used in ecological studies of soil fauna in forest soils.

Insect Migration

(R. A. French)

1957 will probably be shown to have been one of the poorest years for migrant insects in Great Britain since 1930, when the systematic collection of migration records began. In spite of the mild winter of 1956–57 and the fact that some species were observed quite early in the year, the major immigrations that usually take place in late spring and early summer were almost entirely absent. It is, however, possible that there was an immigration of at least one species, *Vanessa atalanta*, at the end of August and the beginning of September. In spite of the large numbers of *Herse convolvuli* and *Acherontia atropos* which were recorded in September and October 1956, there is no evidence that they survived the following winter and produced a further generation.

BEE DEPARTMENT

C. G. Butler

General

During the year the research work of the department has continued along the lines discussed in previous reports. Members of the department have also lectured to scientific societies, beekeepers' associations, etc., have given assistance at short courses for beekeepers and others and have served on various committees, such as the Ministry's Bee Disease Advisory Committee.

In June C. G. Butler reviewed the work of the department on the social behaviour of honeybees at a meeting of the Royal Society.

In July J. B. Free attended the III Congrès de l'Union Internationale pour l'Etude des Insectes Sociaux in Paris and read two papers of his own and one for J. Simpson, who was unable to attend.

During the year Elizabeth Booth resigned in order to devote her time to domestic duties and Yvette Spencer-Booth joined the scientific staff.

Bee Behaviour

Swarming

J. Simpson has made an analysis of records collected from colonies throughout the summer of 1956. These include the sizes of the colonies, the amounts of brood and numbers of queen-cell cups present in them, and the numbers of colonies making preparations to swarm. It is concluded that the tendencies of colonies to prepare to swarm, the amount of brood in colonies and the availability of nectar and pollen in the field all show a similar distribution throughout the summer. Thus the common belief that the maxima of brood rearing, swarming and honey storage form a sequence in the summer cycle of behaviour of honeybee colonies appears to be untrue. The onset of queen rearing appears to occur more frequently in colonies in which the amount of brood is increasing than in those in which it is decreasing, although there is some evidence of a tendency for breeding to decline after queen rearing has begun.

Drifting

The drifting of bees from one colony to another can result in the transmission of disease and, if extensive, can render honey production records, and breeding programmes based on them, useless. J. B. Free has been using marked bees of known ages to study the degree of drifting that occurs in different circumstances.

Young bees making their orientation flights drift the most frequently; established foragers drift comparatively little. But when their hives are moved to new sites considerable numbers of foragers may drift.

In experiments in which the hives in an apiary were arranged in

blocks of four, each hive being at the corner of a square and facing outwards, it was found that bees are more likely to join a colony whose hive is in a corresponding position to their own in an adjacent block than to drift into one of the other three hives in their own block.

When four hives were arranged in pairs (1 foot separating the hives of a pair and 6 feet the pairs) more bees drifted into the hive in the corresponding position to its own in the neighbouring pair than into the other hive of its own pair. Similarly, when four pairs of hives were arranged in a row, eight times as many bees drifted into the hives in other pairs in corresponding positions to their own as into the remaining hives. The bees belonging to the two centre pairs of colonies drifted more than those in the two outside pairs, with the net result that the populations of the outside colonies increased at the expense of the centre ones. Similar results were obtained in experiments in which five colonies were placed singly at intervals of 6 feet in a straight row.

In other experiments small and large colonies were placed side by side and the amount of drifting that occurred between them ascertained. Although on the average more marked bees drifted from the small to the large colonies, so that proportionately more bees drifted from the small colonies than from the large ones, the relative sizes of the colonies were such that the much greater number of bees foraging from the large colonies resulted in net gains in the populations of the small colonies.

In further experiments attempts were made to reduce the amount of drifting that takes place by painting the hives different colours. It was found that when these variously coloured hives all faced the same direction the bees drifted to hives of the same colour as their own very much more than to hives of other colours. When hives all of the same colour faced in different directions the majority of the bees who drifted joined colonies whose hives faced the same direction as their own. When a comparison was made between the number of bees who drifted to hives of the same colour as their own but facing in the opposite direction and the number who drifted to hives of different colour to their own but facing in the same direction, it was found that over five times as many bees drifted into the latter as into the former, demonstrating that, in this connection, the direction in which a hive faces is more important than its colour.

From these and other experiments the practical conclusion was reached that drifting of bees between the hives in an apiary can be reduced to a minimum by arranging the hives in irregular formations, painting them different colours and facing them in different directions. A full account of this work is being prepared for publication.

Orientation to hive

It is commonly believed that if a colony is moved to a new site within foraging distance of the old, many of its bees return to the old site and are lost. J. B. Free has carried out experiments in which colonies containing marked foragers were moved at dusk to new sites 5 yards, 15 yards, ¼ mile and 1 mile from their old ones; no other colonies being situated near the sites from which the experimental colonies were moved.

He found that when colonies were moved 5 yards, an average of 94 per cent of the marked bees successfully returned to their colonies in the new sites, and that at the greater distances an average of over 80 per cent of the bees did so, but in each experiment many of the bees returned to the old site of their colony before proceeding to the new one.

When a colony was moved to a site outside flight range of the old one for a few days before being moved to a site within 15 yards of the original one, fewer bees visited the old site than when the colony was moved directly to a new site.

Queen substance

Although C. G. Butler had obtained strong circumstantial evidence, much of which was of a quantitative nature, in favour of his theory that an adequate supply of a substance which the worker bees of a colony obtain from their queen—"queen substance"—inhibits them from rearing new queens, no direct experimental evidence has been available. This has largely been due to lack of sufficient queens from which to attempt to extract this substance. During 1957, however, thanks to the kindness of Mr. T. Palmer-Jones of the New Zealand Department of Agriculture and of a number of New Zealand honey-farmers, sufficient queens were obtained for extracts to be prepared. It thus became possible for C. G. Butler and Doreen A. Gibbons to demonstrate that an ethanol extract of queen honeybees when given to a group of queenless worker bees, either in sugar syrup on the bodies of a few dead workers attached to a piece of comb or in their drinking-water, was sufficient to inhibit them from constructing emergency queen cells—i.e., from attempting to rear a new queen.

It is tentatively assumed that the effective agent in such ethanol extracts of queen honeybees is identical with the queen substance postulated by C. G. Butler.

A paper describing the results of this work has been prepared for publication.

C. G. Butler has shown that the number of emergency queen cells produced by a queenless colony of honeybees of a given strain is dependent on the number of adult bees present. It has now been demonstrated that the bees obtain some substance from open queen cells containing female larvae and, to a much smaller extent, from sealed queen cells, which inhibits development of their ovaries and the production of further queen cells. This substance is the factor which prevents the worker bees of a colony which loses its queen from producing a very large number of emergency queen cells. It is likely that this substance is very similar to, if not identical with, queen substance.

General Research

Salivary glands

(a) *Mandibular glands.* In experiments in which he fed adult worker honeybees with sugar syrup containing the dye Nile Blue Sulphate, J. Simpson has been able to confirm the finding of Örösi-Pál (Örösi-Pál, Z. (1957), *Bee World*, **38**, 70–73) that with this treatment the contents of the bees' mandibular glands become coloured

blue. His further conclusion that the gland contents are added to wax which the bees manipulate with their mandibles was not confirmed, since new combs built by dye-fed bees were only coloured where coloured syrup was stored in them, other parts of the combs remaining white. Possibly the quantity of dye ingested by the bees was insufficient to colour the contents of these glands strongly enough for the colour to appear in the comb. When bees in cages were fed on candy containing a solution of Sudan III in olive oil it was found that not only the new wax which they produced, but also the bees' bodies and the walls of the cage, became coloured with the dye. Thus the observations of Örösi-Pál that the wax scales secreted by bees fed on this dye are coloured red may well have been due to external contamination rather than to passage of the dye through the wax glands.

(b) *Labial glands.* Although present evidence suggests that the saliva used by worker bees when feeding on dry sugar or thick honey, or when licking their queens, is produced by the labial-gland system (post-cerebral and thoracic glands), J. Simpson has not yet succeeded in demonstrating the function of the oily substance which these glands often contain—particularly in old bees—in addition to the watery saliva.

When a solution of the water-soluble dye Light Green was painted on a queen and allowed to dry the worker bees were able to dissolve it in saliva and remove it easily in a few minutes, whereas when the fat-soluble dye Sudan IV was applied to a queen in the same way, the bees took several hours to remove it and apparently did so by abrasion. No oil could be detected in finely powdered dry sugar which bees had licked nor in the honey-stomach contents of the bees who had been licking it. It was possible to show, however, that some bees had considerable quantities of oil on their tongues. This oil appeared to be held by capillarity between the bristles of the tongue so that perhaps it may not be readily deposited together with the watery portion of the saliva on surfaces the bees are licking. Simpson has suggested that it is possible that the oil is retained by the bristles of the tongue when the saliva is discharged and may serve to keep soft the integument of the tongue and possibly other parts of the bee's body.

The mesh of wire-gauze for queen introduction cages

J. B. Free and C. G. Butler have investigated the size of the apertures in wire-gauze through which bees can feed one another. Worker bees were confined in cages which differed only in the size of the apertures of the wire-gauze from which they were made. The cages of bees were suspended between the brood combs of colonies. After 48 hours the number of bees who had starved to death in each cage was determined. It was found that the bees in the cages were only fed by the bees of the recipient colonies when the apertures in their wire-gauze walls were 2·5 mm. square or larger. It is concluded that cages used to introduce queens to colonies should be constructed of wire-gauze with apertures not less than 2·5 mm. square so that the workers of a recipient colony may be able to feed the queen and lick queen substance from her body while she is inside the cage.

Wax extraction

Beeswax is difficult to extract from old combs in which brood has been reared because it has to be separated from the mass of cocoons left by the bee larvae which have pupated in the combs. The most effective method of separation (other than extraction by a solvent such as chloroform, which is unsatisfactory as it removes an excessive quantity of material other than wax) is to apply pressure to the mass of cocoons under boiling water. Since this method is not popular with small beekeepers, because it is tedious and messy and requires a special wax press and other apparatus, the efficacy of some of the simpler methods that can be used is being investigated by C. G. Butler and J. Simpson. So far, no method has been found which removes as much wax as can be obtained with a press, but some evidence has been obtained which indicates that the efficacy of methods of extraction with boiling water or steam, which normally give very poor results, can be substantially increased if whole combs are treated in such a way that they are broken up as little as possible during the extraction process. Success with this procedure seems to depend on getting the wax of the comb mid-rib to melt and run out without being absorbed by the cocoons.

Pollination

Inge Riedel and Doreen Wort (*née* Gibbons) have studied the adequacy of pollination of field beans on the Rothamsted farm. Under normal conditions only a small proportion of bean flowers give rise to mature pods, and it has been suggested that this proportion would be increased by more effective pollination. However, observations in 1956 suggested that this was not the case, since the initial set of pods on the plants was more than twice the number that reached maturity, thus suggesting that the number of mature pods obtained was the maximum the plants could carry. This hypothesis was verified in 1957. Removal of flowers from those parts of the plants on which most of the pods are normally produced resulted in compensatory increases in the number of pods and beans produced by the remaining flowers.

In another experiment part of a crop of beans was covered with a large nylon screen-cage to exclude bees. Despite the absence of bees, the plants in the cage produced more mature pods and about three-quarters as many beans as the plants outside. The plants inside the cage were taller, however, and the pods they carried were distributed throughout the lengths of their stems instead of being concentrated on the lowest inflorescences as is the normal crop. This suggests that increased growth and development of pods on the upper parts of the plants was made possible by the failure of the lowest inflorescences to produce the normal number of pods because of inadequate pollination. Since, however, the abnormal growth of the plants in the cage may possibly have been due to the conditions in the cage, it is planned to repeat the experiment during 1958 with cages containing colonies of bees as controls.

J. B. Free has continued his experiments to determine the effectiveness of the technique of " directing " bees to crops requiring pollination.

Bee Diseases

Nosema disease

L. Bailey has continued his work on Nosema disease. In the spring 1957 he found that approximately 35 per cent of the department's colonies were infected to some extent with this disease; this was a considerable increase over the percentage infected in the previous spring, despite continued fumigation with acetic acid of spare combs during the intervening period. However, the weather in 1956 was exceedingly poor, and such conditions are known to encourage the development of this disease. Furthermore, during this same period many colonies were frequently, and severely, disturbed in the course of experiments, and this also promotes infection. Comb fumigation has been carried out regularly, however, and it is hoped and expected that infection will be found to have been reduced to a lower level again by the spring of 1958, after the more favourable weather of 1957.

Acarine disease

Further experiments, similar to those described in the last report, were carried out by L. Bailey in 1957. Again it was found that overwintered infected bees died in spring slightly earlier than overwintered non-infected individuals of the same age groups. A marked reduction of infection coincided with the moderately good nectar-flow of 1957, and this agreed with the results of an analysis of records of acarine infection at Rothamsted during the previous few years; it was found, for example, that the proportion of infected colonies had diminished spontaneously and very significantly after the very good nectar-flow of 1955 and had increased significantly after the outstandingly bad season of 1956. During average years, the proportion of infected colonies remained about the same; but in such years the proportion of infected bees in individual colonies varied markedly throughout the active season, rising during periods of nectar scarcity and falling again when the nectar-flow had commenced.

The likelihood of the death of any infected colony, during the winter of 1956–57, appeared to increase if over 30 per cent of its bees were infected, and death seemed certain if 70–80 per cent were infected. But, at Rothamsted, during the past 7 years, even after the worst seasons, no more than 15 per cent of colonies to which no treatment has been applied have had more than 10 per cent of their members infected; the number of colonies with more than 70 per cent of their bees infected in the autumn has ranged between nil and 4 per cent during the last 3 years.

European Foul Brood

L. Bailey has continued his experiments to establish the cause of this disease. He has again shown that this disease only appeared extensively in healthy colonies after cultures of both *Streptococcus*

pluton and *Bacterium eurydice* were sprayed over their brood. Two distinct strains of *B. eurydice* were used; either of which, together with *S. pluton*, caused disease. On one occasion a very limited infection (three sick larvae) occurred in a colony which had been inoculated three times between April and June with heavy doses of pure cultures of *S. pluton*; but *S. pluton* and *B. eurydice* were both isolated from the sick larvae. It was, therefore, considered probable that *B. eurydice* was already present in this colony, and a search was made for the bacterium in many colonies which had not been in contact with disease. As a result, it was found to be commonly present, in summer, in the mouth-parts and honeystomachs of adult bees and in the freshly collected loads of pollen-gatherers; newly emerged bees of the same colonies were not infected with this bacterium. This confirms some of the findings of Burri, although his opinion that *B. eurydice* is converted into *S. pluton*, under unknown conditions, has not been confirmed.

The incidence of *B. eurydice* in adult bees may show a seasonal variation; it appears to be scarce in winter.

The organism does not survive for more than a few days in pollen stored in the hive nor in any medium, such as honey, where it is dormant. It seems likely that *B. eurydice* survives from year to year in the alimentary canals of adult bees, and constantly grows there, possibly obtaining nutriment from pollen which its hosts have eaten.

The reappearance of European Foul Brood in an infected colony in late spring and its rapid decline in late June, or after the start of a good nectar-flow, may be associated with the rate at which larvae, in contact with dormant cells of *S. pluton*, receives *B. eurydice* in the food given them by adult bees. *S. pluton* is able to survive long periods of dormancy—probably for more than a year.

The distribution of *B. eurydice* in "healthy" colonies, its seasonal variation and its geographical distribution in the British Isles are being investigated.

Further attempts to control this disease by feeding infected colonies with quaternary ammonium compounds in syrup were made in the autumn of 1956 with variable results. Some of the treated colonies did not exhibit the disease at all in 1957, others showed no improvement. But all the infected, untreated, control colonies showed the disease again. Variable results were also obtained in large-scale trials in commercial apiaries. Colonies suffering from this disease were much more seriously affected in 1956 than they had been in 1955 when the first, much more successful, trials with quaternary ammonium compounds were made; this may account for the unsatisfactory results obtained after treating colonies in the autumn of 1956. It is possible that these compounds kill *B. eurydice* in adult bees and thereby suppress the disease; but trials have indicated that dormant cells of *S. pluton* on the combs are probably unaffected. In this case, similar results may be expected by feeding antibiotics, such as terramycin, to which *B. eurydice* is sensitive. But if *B. eurydice* is widespread among bees, European Foul Brood may eventually recur. In fact, in 1957 this disease reappeared in one colony which, on being found with the disease, had been fed with quaternary ammonium compounds in

the autumn of 1955 and had shown no trace of the disease in 1956. The well-known suppression of European Foul Brood by antibiotic treatment in spring may in fact be largely due to suppression of *B. eurydice* in the adult bees, although tests have shown that growth of *S. pluton* in cultures is prevented by terramycin. Thus the antibiotic may also exert a direct effect on both organisms growing in the bee larvae.

STATISTICS DEPARTMENT

F. YATES

The scientific staff of the department has remained unchanged, except that Sheila Cohen left to take up a post with Sylvania-Thorne Ltd. There were no new appointments.

N. E. G. Gilbert, statistician at the John Innes Horticultural Institution, has been seconded part-time (from December 1957) to assist in exploring the possibilities of using the electronic computer on the extensive mass of data that has been collected by the Animal Breeding Research Organisation, Edinburgh.

Eight temporary workers were accommodated during the year, four of them from overseas.

THE ELECTRONIC COMPUTER

The electronic computer has played an increasing part in the work of the department, and there has been a very substantial increase both in the volume and range of work. The greater output has been achieved without any marked increase in overtime working, the actual amount of overtime being 33 per cent above normal laboratory working hours, compared with 26 per cent for the period April–December 1956.

The computer itself has continued to give excellent service, and although the figures for reliability are not quite as good as last year, they remain very satisfactory. Details are given in Table 1.

It will be seen that the amount of time devoted to production has substantially increased relative to that devoted to programme checking. This is in part a reflexion of the fact that as our library of programmes has been extended more and more problems can be dealt with by existing programmes, or small modifications of them, and is in part due to increasing efficiency in programme writing and checking.

We have also made good progress in the organization and improvement of the auxiliary equipment on which the operation of the computer depends.

The punched-card reader, brought into operation at the end of 1956, has performed satisfactorily and has proved very useful in processing data already on punched cards, and in particular in the formation of sums of squares and products. We are, however, still awaiting a tape-to-card converter, which has now been on order for some time. Until this is obtained we cannot fully explore the potentialities of the machine for survey analysis.*

A Pye magnetic-tape transport store unit has been presented to the department by the National Research Development Corporation, and work is in progress on linking this up with the machine. The tape store control and power units have now been constructed,

* Delivered January 1958.

but we are still awaiting the delivery of some of the components required to set up the reading and writing circuits. Once this has been done, the specification of the input controls can be completed and their construction undertaken. If this unit proves satisfactory it will considerably extend the range of the machine in computations involving large bodies of data or lengthy programmes.

TABLE 1

Record of machine operation over the period
1 *January*–31 *December* 1957

Details of operation	Hours 1956 *	Hours 1957	Percentage 1956 *	Percentage 1957
System modification (M)	94·3	16·5	5·3	0·6
Scheduled maintenance (S) ...	208·8	323·8	11·7	12·4
Unscheduled maintenance (U) † ...	46·7	209·4	2·6	8·0
Programme checking (C)	574·5	466·6	32·1	17·8
Production runs (P) ‡	757·4	1,430·9	42·3	54·6
Abortive efforts (A) §	47·8	58·9	2·7	2·2
Idle time (I)	58·4	114·9	3·3	4·4
Total machine hours (T)	1,787·9	2,621·0	100·0	100·0
Normal equivalent working hours (N)	1,416·0	1,977·0		

	1956 *	1957
Total time as percentage of normal laboratory time $= \frac{T}{N}$	126·3%	132·6%
% availability $= \frac{C+P+I}{T}$	77·8%	76·8%
% efficiency $= \frac{C+P+I}{T-S-M}$	93·6%	88·2%
% usage $= \frac{C+P}{C+P+I}$	95·8%	94·3%

* 1 April–28 August and 9 October–31 December.

† Unscheduled maintenance breaks down into:
(i) 162·6 hours on the computer.
(ii) 46·8 hours on the peripheral equipment.

‡ Production time breaks down into:
(i) 1305·3 hours on numerical calculation.
(ii) 125·6 hours on programme and library tape organization.

§ Abortive efforts break down into:
(i) 34·0 hours claims against the computer.
(ii) 24·9 hours claims against the peripheral equipment.

In order to improve the accuracy of the punching of the increasing volume of data dealt with by the computer, verification (instead of calling over from a printed record) has been increasingly adopted. Originally it was intended only to verify tapes and insert corrections later, and for this purpose a verifying punch was obtained. This procedure, however, proved unsatisfactory, particularly when handling large amounts of survey data, such as that of the Survey of Fertilizer Practice. The verifier has therefore been linked with an old output punch, and this assembly can verify, verify and re-punch, or punch, thus enabling an edited tape to be produced during verification. This system has shown itself to be reliable and trustworthy

and is now used for the preparation and checking of all the Survey of Fertilizer Practice tapes.

To reduce the amount of punching required for survey and similar extensive data the field use of marked-sensed punched cards is being investigated.

We have been considering possible methods of increasing the immediate access storage of the machine. (At present, apart from the accumulator and double-length register, there are only three single-word immediate access registers.) While it is unlikely that any very extensive modification will be an economic proposition, one very simple and attractive scheme which will add a further three immediate access registers without requiring any alterations to existing programmes appears to be possible. This will utilize the space in the cabinets made available by the new single-plate delay lines. These are being fitted in place of the old lines, which were giving increasing trouble. If this modification proves possible it will simplify the programming, increase speed and somewhat cut down the number of orders.

The life test on the special quality valves instituted last year has continued. At the end of 1957 less than 5 per cent of the ordinary valves included for comparison were still in service, whereas of the special-quality valves only about 7 per cent have been rejected. Some of these latter valves have now been in the computer for more than 4,000 hours. Special-quality valves suitable for computer use are now being manufactured as a standard line.

Satisfactory progress has also been made in the preparation of programmes. In addition to programmes prepared for specific jobs a number of new general programmes for performing statistical analyses of various types have been prepared, some of them of considerable complexity.

Experimental Design and Analysis

Yates and Patterson carried out a preliminary examination of the results so far obtained in the six-course rotation experiments on varying levels of nitrogen, phosphate and potash at Rothamsted and Woburn, with particular reference to the estimation of errors and the possible relationships of responses to weather. A report of this examination is being published (12.9). An examination of the results of the Woburn ley–arable experiment undertaken by Dr. H. H. Mann and Boyd has been completed and a paper is in the press (12.4).

Boyd has carried out a thorough investigation of the differences in fertilizer responses of crops grown with and without farmyard manure. This has thrown considerable light on the somewhat curious results obtained by Crowther and Yates (" Fertilizer Policy in Wartime ", *Emp. J. exp. Agric.* 1941), who found that the responses to inorganic nitrogen in the presence of farmyard manure were almost the same as those in the absence of farmyard manure. It appears that Crowther and Yates's findings were due to the poor performance of nitrogen at the low levels of phosphate and potash existing on many of the plots without farmyard manure, and that at adequate levels of phosphate and potash the response to nitrogen is

considerably reduced by farmyard manure. A paper has been prepared, and will shortly be submitted for publication.

Boyd acted as joint author of the section on cultivations and manuring of the third edition of the Ministry of Agriculture's bulletin no. 94, on the growing of potatoes (12.1).

We have continued close collaboration with the National Agricultural Advisory Service (N.A.A.S.) on the design of crop and animal experiments. Patterson and Westmacott have been particularly concerned with this work. Boyd and Joan Anderson summarized the results of 38 $3 \times 3 \times 3$ NPK experiments on potatoes for the Soil Chemists of the N.A.A.S. Eastern Region. A report on this

TABLE 2

Analysis of experiments on the electronic computer

	(*a*) Number of experiments		(*b*) Number of variates	
	1956	1957	1956	1957
Rothamsted and other institutes ...	185	413	649	1,723
National Agricultural Advisory Service	309	623	784	3,030
National Institute of Agricultural Botany	189	217	268	288
Total	683	1,253	1,701	5,041

Details of variate analyses (1957)

	Randomized blocks and split plots	Latin squares	3^3	2^n
Rothamsted and other institutes ...	1,364	133	88	138
National Agricultural Advisory Service	1,961	554	205	310
National Institute of Agricultural Botany	288	—	—	—
Total	3,613	687	293	448

has been drafted and is under discussion with the Regional Officers. We have also done work for the Pea Growing Research Organisation and the Sea-Flooded Land Conference, and have collaborated closely with the Agricultural Research Council (A.R.C.) Statistics Group at Cambridge in the design and interpretation of experimental work on animals.

Leech prepared a report on the analysis of the 1956 field trials on chemical sterilizers for milking machines. These trials were organized by the National Institute for Research in Dairying (N.I.R.D.), and this report, together with the results of the laboratory tests at Shinfield, provided the basis on which the Ministry of Agriculture decided which materials should be finally approved.

We are still extending the use of the electronic computer in the analysis of replicated experiments, and the volume of work dealt with this year has shown a very substantial increase over that of last year. The number of experiments handled has been doubled and the number of actual analyses carried out has trebled. Four factors have contributed to this increase. First, because of the extension of our library of programmes the number of types of design which the electronic computer is capable of handling is steadily increasing.

Secondly, the number of research stations sending us work has somewhat increased. Thirdly, many of those who in the first place had current experiments analysed have subsequently asked if we could deal with some of their accumulated backlog of work which has been lying around awaiting analysis. Fourthly, many workers have taken the opportunity of having more thorough analyses done on the ancillary observations taken in the course of their experimental work. This last explains the greater increase in the number of variates analysed than in the number of experiments handled. The table on p. 178 shows the actual number of experiments handled and the numbers of analyses carried out (each variate analysed and each covariance analysis being reckoned as one unit). Great credit is due to Dunwoody and Emily P. Simpson for organizing the coding and punching of the large volume of experimental data handled this year.

Surveys

In 1956 the Fertilizer Manufacturers' Association suggested that they might co-operate in the Survey of Fertilizer Practice, thereby enabling it to be extended to a considerably larger number of districts. A joint scheme was consequently evolved for the 1957 survey, covering in all forty-five counties or parts of counties. Fifteen of these have been surveyed by the staff of the N.A.A.S. Regional Soil Chemists and the remainder by the representatives of the Fertilizer Manufacturers and Merchants.

Since this extension of the survey would have presented serious computing problems if handled by the previously current methods, it was decided to see if the work could be transferred to the electronic computer. This transfer was successfully effected by H. R. Simpson, who has been in charge of the whole of the electronic side of the work. This achievement marks a major step forward in the utilization of the machine for survey analysis. The speed of analysis has been more than doubled, which has proved particularly valuable because of the late arrival of much of the data. As an example, the results for two districts covering some 1,500 fields received on Monday, 9 December, were available the following Friday. If our ideas of using mark sensed cards for the recording of the original field data prove practicable the time of analysis should be further substantially reduced. It is intended to give this idea a field test in 1958.

A further advantage of the use of the machine is that once the tapes have been prepared additional analyses can be carried out by the machine very quickly. Thus for certain districts estimates have been obtained for straight and compound fertilizers separately; a programme has also been written which will produce a breakdown by previous crop and other factors.

A preliminary report based on the thirteen districts for which data had then been received was issued on 19 December (12.10).

The results so far available have allowed a close study to be made of farmers' current use of fertilizers, and at the same time information is being obtained from a number of districts not previously covered by survey. In the period 1953–57 overall consumption of fertilizers in England and Wales increased by about one-

quarter for nitrogen and one-half for potash, with little change for phosphate. The results so far available show that in all parts of the country the largest increase in consumption of nitrogen and potash per acre has taken place on arable crops. There have also been substantial increases on leys, but as yet there has been little change in the treatment of permanent grass, especially in those parts of the country where the acreage of permanent grass is large.

We have co-operated extensively with the National Institute of Agricultural Engineering in the design and analysis of various surveys. Much of this work has been done on the electronic computer and punched-card equipment.

The Ministry of Agriculture, Fisheries and Food (M.A.F.F.) has now started a survey on a national scale of the diseases of dairy cows. The sample of 1,500 herds for this survey was planned and drawn here except for the small samples for the Inverness and Aberdeen areas (12.3). Leech (and on the programming side, H. R. Simpson) have also continued the analysis of the results of the surveys of diseases of dairy cows in limited areas that had already been completed under the supervision of Dr. F. W. Withers. The analysis is now complete except for a critical analysis of certain results for which a programme for dealing with multi-way tables of quantal observations had to be written. A report with Dr. K. C. Sellers on the analysis of the second year of the survey of losses in breeding ewes in Yorkshire and Lancashire is in a similar position. The required programme (Yates and Leech) has now been completed. It is an extension of a programme for the analysis of multi-way tables of quantitative observations with unequal weights which has also been written (Yates).

Leech also assisted in the planning and analysis of several other investigations. The M.A.F.F., Health Division, was helped with the design of a system of records for a large field trial on a vaccine against Johne's Disease. The private cattle-breeding centres were advised on the planning of survey work into the factors affecting the fertility of cattle in Devon and Somerset, and some data were analysed on their behalf. A pilot survey of factors affecting cow fertility was also planned in co-operation with Dr. K. C. Sellers, Director of the Animal Health Trust, Farm Livestock Station. This survey was carried out through cattle-breeding centres operated by the Milk Marketing Board, and the results should indicate whether or not such a survey would be worth while and practicable on a larger scale.

Entomology

H. R. Simpson has continued to collaborate with Mr. W. H. Potts of the Colonial Office Tsetse Committee in a study of the possibility of tsetse control by the release of large numbers of male flies sterilized by gamma irradiation (12.7). He has also assisted Mr. J. Bowden of Ghana in the analysis of some survey data on the Cacao Capsid. This involved fitting negative binomial distributions, for which a programme was written for the machine.

Marjory G. Morris has continued her co-operation with members of the Entomology Department. In particular she has co-operated

with R. M. Dobson on studies of the emergence and longevity of adults of the wheat-bulb fly. A joint paper is being prepared. She has also carried out analyses on experimental data on the frit fly of oats for the N.A.A.S. and of some frit-fly data for the Entomological Department of the Imperial College of Science.

Genetics

We completed the work for Dr. J. W. B. King, Animal Breeding Research Organisation, Edinburgh, on the data on pigs from the Danish Progeny Testing Stations. The last part of this work was much facilitated by its transference to the electronic computer when the card reader became available (Westmacott). As mentioned in the General section, we have recently made arrangements for undertaking more extensive computing work for this organization.

Gower has continued his work with Dr. E. C. R. Reeve, Institute of Animal Genetics, Edinburgh, on the effect of linkage and selection in in-breeding (12.6). He has also undertaken a Monte-Carlo type investigation into population changes when two competing species are present for Dr. P. H. Leslie, Bureau of Animal Population, Oxford. Two models were investigated, and a paper describing the results will be prepared.

H. R. Simpson completed his work in co-operation with Dr. J. H. Renwick, Galton Laboratory, on the estimation of linkage from a variety of human pedigree data (12.8).

Colonial Work

We have continued our advisory work for Commonwealth workers and have done some work on the electronic computer. Three Commonwealth workers have studied in the department for varying periods.

Other Work

Gower has written a programme for G. Brown (Pedology Department) for the calculation of indices and interplanar spacings of X-ray reflexions from the cell constants of crystals. The use of this programme disclosed some errors in a book which Brown is editing. J. H. Rayner (Pedology) gave a short account of our crystallographic programmes to the Conference on Biological Structures and Computational Methods held in London, 1956 (see above, p. 67).

Lipton has developed a programme for fitting the logistic curve

$$y = A - \log_e(1 + Be^{-kt})$$

This was required by Mr. J. A. Nelder of the National Vegetable Research Station. He has also written a programme for evaluating the integral of the bivariate normal distribution over a non-rectangular region, required by Dr. P. S. Hewlett (Pest Infestation Laboratory, D.S.I.R.) and Dr. R. L. Plackett (University of Liverpool) in their development of a unified mathematical theory for quantal responses to mixtures of drugs (*Nature, Lond.* **180**, 712,

(1957)). Lipton and Nelder are also carrying out an investigation into the Newton–Raphson iterative procedure for solving least-square equations.

Healy has continued to assist various medical departments, including Birmingham University Department of Anatomy, The Nuffield Blood Group Research Centre, the London University Institute of Child Health and the Central Public Health Laboratory. C. C. Spicer of the Central Public Health Laboratory has been studying the programmes and use of our machine with a view to utilizing it on various problems with which he is concerned.

Lipton has continued his work with Dr. K. L. Blaxter of the Hannah Dairy Research Institute on the Cattle Efficiency Project of the Agricultural Research Council. There is, however, a good deal more to be done before the value of the project can be finally assessed.

Lipton also carried out an investigation into the relation between the length of sampling interval and the accuracy of the estimation of milk production in conjunction with Mr. L. K. O'Connor of the Milk Marketing Board. Systematic sampling of milk yield, fat yield and solids-not-fat yield at intervals of 7, 14, 28, 42, 56 and 63 days was carried out on each of eighteen lactations. A preliminary report on the accuracy of estimating lactation fat per cent has been published (12.5). A more detailed paper dealing with other estimates is being prepared.

Overseas Assignments

Yates spent two and a half months in India during the winter of 1956–57. The first month was spent at the Indian Statistical Institute as a member of an International Review Committee set up to review the work of the Indian National Sample Survey. The other members of this Committee were Sir Ronald Fisher, Dr. M. H. Hansen (U.S.A.), Professor T. Kitagawa (Japan) and Professor A. Linder (Switzerland). The last 6 weeks were spent at the Statistical Wing of the Indian Council of Agricultural Research, New Delhi, making a review of the progress of the agricultural research programme on which he and Dr. Finney advised three years previously. Yates also attended the Third Meeting of the Sub-Commission on Agricultural Research of the F.A.O. European Commission on Agriculture which met in Paris during April.

Church completed his assignment in Ethiopia, where he was organizing sample surveys for the collection of basic agricultural statistics.

Patterson is at present on a 6-months visit to the Institute of Statistics, North Carolina. He is mainly engaged on advisory work on crop experiments and research on change-over trials in animal husbandry experiments.

Conferences, Lectures, etc.

The year has seen the establishment of the British Computer Society. Yates is a member of the Council of the Society and Rees is a member of a number of its Committees. Rees took part in

much of the preliminary discussion prior to the formation of the Society.

A number of members of the department have given lectures on scientific and statistical matters.

Healy and Lipton attended the 30th Session of the International Statistical Institute, which was held in Stockholm in August.

A course on statistical method was given by members of the department at the end of January to members of the staffs of the N.A.A.S. Experimental Husbandry Farms and Experimental Horticulture Stations. The course lasted a fortnight, and there were sixteen participants.

FIELD EXPERIMENTS SECTION

The field experiments at Rothamsted and Woburn are controlled by the Plot Committee consisting of the following members of the staff: F. Yates (Chairman), H. V. Garner (Secretary), F. C. Bawden, G. W. Cooke, J. R. Moffatt, C. A. Thorold, R. G. Warren and D. J. Watson. Most of the long-term experiments were planned and designed by the Plot Committee, but proposals for short-term experiments are received from workers in the scientific departments and, after examination by the appropriate Working Party, are passed on to the Committee for approval.

In addition to these full-scale experiments a number of problems are studied on microplots laid down in various enclosures on both farms. In most cases the work on these small plots is carried out by the scientific departments.

The number of full-scale plots carried out by the experimental staff on the two farms in 1957 and some totals for the last 10 years are given in Table 1.

TABLE 1

	Grain	Roots	Hay	Grazing	Total
Classical experiments:					
Rothamsted	303	177	47	—	527
Woburn	—	—	—	—	—
Long-period experiments:					
Rothamsted	343	342	187	96	968
Woburn	173	250	55	12	490
Annual experiments:					
Rothamsted	676	270	112	—	1,058
Woburn	192	164	—	—	356
Total	1,687	1,203	401	108	3,399
1948	817	558	103	3	1,481
1951	888	1,011	438	108	2,445
1954	1,104	1,027	470	108	2,709
1957	1,687	1,203	401	108	3,399

The number of plots has more than doubled since 1948, and in the last two seasons has stood at about 3,400. Until 1952 cereals, roots and hay plots all increased in step, but with the introduction of the combine-harvester in 1952 on an experimental scale, and its almost general adoption in 1954, the number of cereal plots continued to rise while the others were stabilized at about the 1952 level. At present cereal plots account for half the total.

Although the Rothamsted land in all is 603 acres, it is by no means entirely occupied by experimental plots, nor is the whole of the area suitable for this purpose. The present partition of the acreage is estimated as closely as possible in Table 2.

The non-agricultural area, amounting to one-fifth of the whole, includes roads, woods, allotments, buildings and the Manor grounds.

Farmland unsuited to experiments takes in the headlands of fields, land shaded by trees, dell holes and steep slopes; it amounts to over a quarter of the estate. Thus about half the area is classed as potential experimental sites. One-fifth of this is permanently occupied by classical and long-period experiments, and even when these are discontinued the sites are not likely to come into use again for many years. There remain 249 acres of land to accommodate the annual experiments and any new long-term ones. Of this only 85

TABLE 2

Utilization of the land in the Rothamsted Estate 1957

	Acres	%
Total area	603	100
Non-agricultural area	126	21
Farm-land unsuitable for experiments	163	27
Land available for experiments	314	52
Experimental land	314	100
Classical experiments	38	12
Long-term rotation experiments	27	9
Land suitable for tests of potash and phosphate ...	85	27
Suitable for nitrogen and pathology experiments ...	164	52

acres are sufficiently poor in phosphorus and potassium to accommodate critical experiments on these nutrients. The remaining 164 acres can be used either for experiments involving nitrogen, crop varieties or field experiments on plant diseases.

The weather for 1957 is described in the report on the Farms; the following is a summary of its main features. The autumn of 1956 was unusually dry till well into December; consequently the arrears of cultivations that had built up during the long slow harvest were gradually overcome; but it was late in November before all the winter wheat was sown. The most remarkable feature was the mild winter: the period December to February inclusive was very warm, rather wet and singularly free from frost. On the heavy land this gave the worst spring seedbeds for many years. The drought which set in in March did not improve matters, for the land baked very hard so that potatoes went in rough and roots had to wait some weeks for softening showers. April and May continued very dry and, although bad for spring corn, were excellent for hoeing. June and July had normal rainfall, but it was well into summer before the effects of the drought began to wear off. When harvesting started in earnest in mid-August it continued practically without a check, though most of the grain needed drying. Ploughing made good progress in September and the first fortnight of October gave ideal weather for potato lifting. The weather then became showery though still warm, and the land was very sticky when mangolds and sugar beet were lifted. Harvesting of these crops was completed by the middle of November.

THE CLASSICAL FIELDS

Broadbalk

The field was drilled on 12 November in a seedbed that was rather wet, but just dry enough to cover the seed. Germination

was rapid, and the plant was very forward and green all through the winter. In early spring there was the usual attack of wheat-bulb fly (*Leptohylemyia coarctata*), particularly on Section Ib after fallow, the infestation ranging from 15 to 65 per cent. Nevertheless, this section yielded considerably more than any other. The crop was too well established to be affected by the spring and early summer drought. On 16 May the continuous wheat area in Section I, now carrying its sixth crop, was sprayed with MCPA, this being the first occasion that a weedkiller had been used on Broadbalk. This operation was very effective, and in addition to reducing the broad-leaved weeds, the spray checked the growth of common vetch (*Vicia sativa*), which in recent years has been so prevalent on Plots 2, 5 and 6, where the nitrogen level is low. On the parts of these plots where fallowing is practised the vetch was so prevalent that it competed seriously with the crop, especially on Sections III and IV.

Take-all (*Ophiobolus graminis*) was prevalent on some of the plots this year, particularly on Plot 8, Section Vb, which had received 5 tons of chalk/acre in the autumn of 1956 and its annual dressing of complete fertilizer including 6 cwt. of sulphate of ammonia. This treatment usually gives one of the highest yields on Broadbalk, but this year the limed section only yielded 7·1 cwt. of grain, as compared with 19·0 cwt. on the neighbouring section with the same fertilizer but without the 1954 lime dressing. The effect corresponded closely with the plot boundaries and is being more closely studied in pot culture to discover the factor responsible for the heavy incidence of take-all.

The crop stood well until the end of July, but from then onwards it began to look increasingly untidy, partly due to straggling caused by eyespot (*Cercosporella herpotrichoides*), which always occurs, and partly due to the damage to the ears by small birds. Before harvest lodging was severe on the section after fallow, on the dunged plot and on Plot 8 with heavy nitrogen; elsewhere it was more distributed, Plot 16 being one of the worst.

The harvest of 1957 was a notable one on Broadbalk, for the combine-harvester was used for the first time. For a parallel innovation one has to go back to 1901, when the binder took over from the traditional band of reapers. The plot yields in 1957 were measured by a single cut with a 10-foot Massey Harris self-propelled machine taking about half the manured area. The outside rows, which are usually more or less abnormal, were excluded. The combine handled lodged plots well and cut a stubble of about the usual height, but some discontinuity in straw yields was inevitable because the chaff and small cavings, formerly measured from the threshing-machine, could not be collected and weighed. The effect of combine-harvesting on weed infestation will be kept under observation.

Wild oats on Broadbalk have shown a steady decrease in the past 6 years as a result of systematic hand-pulling. In 1957, however, there was a noticeable increase. This situation is being closely watched.

Broadbalk Wilderness

The North half of the Wilderness, which has been kept clear of bushes since 1882 but otherwise left entirely undisturbed, was

divided into two sections in the spring of 1957. One part has continued under the usual system to show the unchecked growth of grasses and weeds; the remainder has been mown repeatedly throughout the season without removing the cut material. The changes in the balance of species under the different systems of management are being studied by the Botany Department.

Hoosfield

The permanent barley plots were drilled on 6 April; this rather late sowing caught the full effect of the drought. As always happens on the classical experiments in a dry spring, the dunged plots showed much better early growth than the others, and this year the fertilizers never caught up. The dunged plot was obviously the best, and was the only one which lodged before harvest. On the whole yields were poor; the best of the plots without organic manure were rather thin and short. Once more the whole field was pulled for wild oats and the full area of every plot was harvested. In order to reduce coltsfoot, thistles and other perennials that were beginning to become conspicuous, it was decided to spray with MCPA in 1957 instead of DNOC, which had been used since 1944.

Barnfield

The permanent mangold field was too dry to drill till 17 May. The plant came well, and singling started on 9 July, with the dunged plots well in advance of the rest. Owing to shortage of staff, it was possible to single only four rows of mangolds and four rows of sugar beet per plot; the remainder of the crop was discarded. The plots carried a fairly good plant after singling, and in the cool moist weather that followed growth was rapid. There was no real check for the rest of the season, and yields were above average. Lifting began towards the end of October, and the reduced acreage was completed within a fortnight under rather wet conditions.

Park Grass

After a very mild winter the Park Grass plots started the season with an unusually heavy growth of grass. On 18 June this gave a first cut well above the average; the crop was baled and weighed in very favourable weather only 4 days after cutting. The bare patches, caused by the frost and spring drought of 1956, on the very acid plots were almost completely recolonized during the growing season of 1957. Once more white clover was more than usually conspicuous in the plots without added nitrogen. A rather heavy second cut was taken and weighed green on 26 September.

Agdell

The crop of winter beans grown without manure in 1956 showed such large effects due to the residues of phosphate and potash applied to the old rotation that it was decided to look once more for residuals. This year the crop was potatoes, and a heavy dressing of 5 cwt. of sulphate of ammonia was given to every plot. Ulster Supreme potatoes were planted rather late, 27 April, since it was very difficult to obtain a satisfactory tilth. After a late start the crop on the plots that had formerly received fertilizer grew well, but

on the former unmanured plots the growth was very poor indeed, each plant producing one fair-sized tuber but no chats, with a total yield of about 3 tons/acre. Elsewhere the yield was very good and consisted of a small number of large tubers on each plant. The best plots gave 15 tons/acre.

Exhaustion Land

From 1949 to 1956 the plots of the Exhaustion Land had carried eight crops of continuous barley with a basal dressing of 0·5 cwt. N. The yields showed marked residuals from phosphate, potash and dung applied to the old potato experiment which formerly occupied these plots and ended in 1901. Much work on the soils and crops has been carried out in the Chemistry Department. In 1957 for the first time the cropping on the original strips has been widened to include sugar beet, potatoes, kale, swedes, spring wheat and barley. Additions of phosphorus and potassium have been given to all crops on a microplot scale so that the residual effects can be evaluated in terms of direct additions.

The behaviour of the various crops under phosphate deficiency was very striking. All harvesting and sampling of this experiment has been undertaken by the Chemistry Department.

Long-period Experiments

Deep-cultivation rotation

The last two crops in this experiment were harvested this year; they were 1-year seeds hay and wheat. The experiment has now ended, and the whole site has been sown uniformly with wheat to provide material for foot-rot observations following several different crop sequences. A summary of the results from two complete rotations of this experiment are given on pp. 193–199 below.

Ley–arable rotations

The season was rather unfavourable for the establishment of young grasses. The 1-year hay on Highfield was killed under a lodged nurse crop of barley and had to be resown in spring 1957; it gave only about half the yield of the corresponding undersown crop on Fosters. The sowings of leys, cut grass and lucerne made in the open ground in spring 1957 had a very poor start in the drought, and in spite of the rain that came in mid-summer they never reached the normal level of yield. The first year of the 3-year grazing lay in Fosters was particularly poor. Seeds in their second year were much nearer average, but the third-year grazing leys on both fields were abnormally poor, for they produced only 21 cwt. of dry matter for the whole grazing season, which is half the mean yield of the last 7 years. Grazing began early this year on account of the very mild winter. The sheep were on the plots by mid-April, but after one or two rounds they had to be taken off because of the dry weather. The grazing season extended into October, when grass was again very plentiful. The yields of the herbage crops in cwt./acre are given in Table 3.

The yield of third-year lucerne in Highfield was abnormally low. The two plots in question had been noticeably affected with lucerne

wilt (*Verticillium*) in their second year, 1956, and had been sprayed with TCA (sodium trichloroacetate) in winter 1956–57. Some *Sclerotinia* was also found. The amount of *Verticillium* found in 1957 was probably insufficient to account for the whole damage, but plants weakened by *Verticillium* may have been further repressed by the spraying. Nitrogen responses were high on Highfield cut grass, the double dressing of 2 cwt. "Nitro-Chalk" per cut giving about 17 cwt. dry matter/acre more than the single dressing. Slightly lower but still satisfactory returns were obtained from Fosters. The grazing grass, which received much lighter dressings of "Nitro-Chalk", gave a slight gain of 5 cwt. dry matter on Highfield as measured by pasture cuts, but much less on Fosters.

TABLE 3

Rothamsted ley–arable experiment: Highfield and Fosters
Yield of herbage crops

(Dry matter, cwt./acre)

	Old grass		Reseeded grass		3-year ley	Cut	Cut	1-year
	Hay	Grazing	Hay	Grazing	grazing	grass	lucerne	hay
			Highfield (formerly old grass)					
First-year blocks...	72·2	20·5 *	40·4	19·7 *	30·2	46·5	32·6	24·7
Second-year blocks	—	27·7	—	30·5	38·7	74·4	92·6	—
Third-year blocks	—	29·5	—	30·8	21·3	54·8	63·0	—
			Fosters (formerly old arable)					
First-year blocks...	—	—	19·3	21·7 *	18·2	34·0	24·7	44·3
Second-year blocks	—	—	—	21·2	38·2	56·4	92·6	—
Third-year blocks	—	—	—	26·8	21·1	46·1	98·4	—

* Aftermath grazing.

The test crops, whose yields are used to evaluate the effect of the various leys on soil fertility, were all satisfactory in 1957. Yields were surprisingly similar on both fields, Highfield now 9 years out of grass and Fosters with a long arable history. Proctor barley yielded over 2 tons of grain, Yeoman wheat gave 35 cwt. and Majestic potatoes about 12 tons/acre. The effect of the leys on the three test crops are given in Table 4.

The most remarkable figure in the table of wheat yields for Highfield is the yield after cut grass, which this year was practically as good as any other treatment. In former years cut grass has been noticeably poorer than the rest as a preparation for wheat. In 1956, for example, wheat after cut grass yielded 19 cwt./acre less than wheat after arable crops only. This bad effect of cut grass has never been observed on Fosters. Once more on Highfield the purely arable sequence has given the highest yield; on Fosters, however, the lucerne continues to be the best preparation for wheat. Highfield showed small but definite improvement due to doubling the rate of "Nitro-Chalk" top-dressing; in previous years the extra nitrogen had caused a depression. Fosters, as always, gave a good response to extra top-dressing.

The second-year test-crop potatoes on Highfield showed the usual superiority of the 3-year grazed ley, with the arable rotation 2 tons behind. On Fosters, however, the potatoes after arable cultivation were the best, and on the average of the last 6 years they have been as good as any. The differences in behaviour of

the two fields is probably in part due to the supply of readily available potash. In Highfield it is low, as is shown by the big response to dung and to extra muriate of potash on all treatments except the ley. In Fosters it is high; only after lucerne is there evidence

TABLE 4

Rothamsted ley–arable experiment: Highfield and Fosters
Yield of test crops, 1957

	S.E.	After 3 years' cropping with: Lucerne	Grazed ley	Cut grass	Arable crops	Mean	S.E.
First test crop:							
Wheat, grain, cwt./acre—							
Highfield		35·3	30·9	35·9	38·2	35·1	
Effect of 0·3 cwt. N ...	±1·91	+4·8	+1·0	+2·1	+0·8	+2·1	±0·96
Fosters		40·6	33·4	33·2	35·4	35·6	
Effect of 0·3 cwt. N ...	±1·12	+2·6	+3·0	+4·0	+5·0	+3·7	±0·56
Second test crop:							
Potatoes, tons/acre—							
Highfield		13·18	14·24	12·25	11·98	12·91	
Effect of 12 tons dung...	±0·682	+1·47	+0·14	+1·54	+1·69	+1·21	±0·341
Effect of 0·5 cwt. N ...	±0·682	−0·08	+0·08	+0·69	+0·98	+0·42	±0·341
Effect of 0·9 cwt. P_2O_5...	±0·355	0·00	+0·04	+0·06	−0·40	−0·08	±0·178
Effect of 0·9 cwt. K_2O...	±0·355	+1·84	+0·60	+1·78	+1·24	+1·37	±0·178
Fosters		12·39	11·66	11·15	12·67	11·97	
Effect of 12 tons dung...	±0·503	+1·34	+0·62	+0·57	+0·87	+0·85	±0·252
Effect of 0·5 cwt. N ...	±0·503	−0·92	−1·24	−0·27	+0·57	−0·46	±0·252
Effect of 0·9 cwt. P_2O_5...	±0·459	+0·96	+0·10	+0·04	−0·47	+0·16	±0·229
Effect of 0·9 cwt. K_2O...	±0·459	+1·26	+0·48	+0·29	+0·11	+0·54	±0·229
Third test crop:							
Barley, grain, cwt./acre—							
Highfield		45·3	44·4	46·3	45·4	45·3	
Effect of 0·2 cwt. N * ...	±2·18	−0·7	−3·8	−0·3	+0·3	−1·1	±1·09
Fosters		43·7	42·4	42·8	41·2	42·5	
Effect of 0·2 cwt. N ...	±1·05	−0·9	+0·7	−0·1	+2·1	+0·5	±0·52

Note: The fertilizer effects are the increases of the double dose of nutrients above the single dose; i.e., the effect of 0·5 cwt. N to potatoes is 1·0 cwt. N–0·5 cwt. N.
* No single dose of nitrogen in this case.

of a response to extra potash. The economy of potash due to 3 years grazing is of little advantage to potatoes on this field. Doubling the phosphate has been ineffective on both fields.

The third test crop, barley, was so heavy that none of the pre-treatments showed any marked effect.

ANNUAL AND SHORT-PERIOD EXPERIMENTS

These experiments continue for several seasons but occupy a new site each year. For fertilizer tests sites must be chosen that are not too rich in the nutrients in question, and this usually involves some restriction in the manuring of potential sites in the years when they are not under experiment. For the field study of pathology problems it is usually sufficient to provide the experimenters with well-grown crops; consequently part of the farm in high fertility is reserved for this work. A brief note on the type of problems studied in 1957 is given below.

Fertilizer experiments

(1) Winter wheat, Great Knott I. A comparison of eight varieties at 2 and 4 cwt. of sulphate of ammonia/acre.

(2) Spring wheat, Little Hoos. "Nitro-Chalk" at three rates, 2, 4 and 6 cwt./acre, in seedbed, as early top-dressing and as late top-dressing. Both single and divided dressings were tested. Variety: Koga II.

(3) Spring wheat, Great Knott III. A comparison of seven varieties at 2 or 4 cwt. of sulphate of ammonia/acre.

(4) Spring wheat, Little Hoos. A test of sulphate of ammonia at several rates, combine-drilled or broadcast. All plots had phosphate and potash combine-drilled; some had in addition 0·22, 0·54, 0·68 cwt. N as sulphate of ammonia combine-drilled (as appropriate granular compounds); the controls had the same amount of nitrogen broadcast on the seedbed before drilling.

(5) Barley, Great Field II. Farmyard manure and all combinations of N, P and K were applied to potatoes in 1956. The residues of N and P were evaluated in barley in terms of direct applications of sulphate of ammonia and superphosphate. Variety: Proctor.

(6) Barley, Great Field II. Farmyard manure and all combinations of N, P, K and salt were applied to sugar beet in 1956. The residues of N were evaluated in barley in terms of a direct application of sulphate of ammonia. Variety: Proctor.

(7) Barley, Great Field II. A comparison of five varieties at 0 and $1\frac{1}{2}$ cwt. of sulphate of ammonia/acre.

(8) Barley, Little Hoos. Levels of nitrogen and time of application as in spring wheat (2). Variety: Herta.

(9) Barley, Little Hoos. Combine-drilling of sulphate of ammonia as in spring wheat (4). Variety: Herta.

(10) Oats, Fosters. A comparison of eight varieties at 0·36 and 0·72 cwt. N.

(11) Beans, Great Harpenden II. A comparison of autumn-sown and spring-sown beans, including a test of three levels of phosphate and three levels of potash in all combinations. Spraying against aphids was also tested. Varieties: S.Q. Giant and Spring Tick.

(12) Potatoes, West Barnfield II. Farmyard manure at 0, 5, 10 and 20 tons/acre in all combinations with 0·9 cwt. N as sulphate of ammonia, 0·75 cwt. P_2O_5 as superphosphate and 1·5 cwt. K_2O as muriate of potash. Variety: Majestic.

(13) Sugar beet, West Barnfield II. As potatoes experiment (12), including a test of 5 cwt. agricultural salt/acre. Variety: Kleinwanzleben E.

(14) Lucerne, Great Harpenden II, third year. Three levels of muriate of potash, 1, 2, 3 cwt. K_2O/acre, either in a single dressing in 1955 or in three equal annual dressings in 1955–57. Variety: Du Puits.

(15) Ryegrass, Long Hoos I, second year. Formalized casein, casein, urea, calcium nitrate and ammonium sulphate at 0·75 and 1·5 cwt. N/acre.

Pathology experiments

(16) Winter wheat, Pennells Piece (R. Bardner, Insecticides Department). Test of various insecticides broadcast or combine-drilled against wheat-bulb fly (*Leptohylemyia coarctata* Fall.) on wheat after bare fallow.

(17) Various cereals, Hoosfield, old four-course land (M. D. Glynne, Plant Pathology Department). Effect of various crop sequences on the incidence of foot rots on barley, oats and three varieties of winter wheat.

(18) Cereal–bean rotations, Great Field I, first year (M. D. Glynne, Plant Pathology Department). The first year of a number of different rotations involving cereals and beans in preparation for a test crop of wheat in 1960. Detailed observations on foot-rot diseases are being made.

(19) Spring wheat, Highfield I, second year (G. A. Salt, Plant Pathology Department). Effect of take-all (*Ophiobolus graminis*) and of weeds on yield. The weeds were controlled on certain plots by herbicides or by hand hoeing. The cropping in 1956 was designed to set up differences in the incidence of take-all.

(20) Spring beans, Long Hoos V (M. J. Way, Insecticides Department). Field studies on bean aphis (*Aphis fabae*). Spraying early and late on crops sown at four dates in spring.

(21) Spring beans, Deacons (M. J. Way, Insecticides Department). Field studies on bean aphis. Several insecticides tested at high and low volume.

(22) Potatoes, Highfield IV (J. M. Hirst, Plant Pathology Department). Test of copper fungicide against late blight (*Phytophthora infestans*).

(23) Potatoes, Long Hoos VII and III (D. H. Lapwood, Plant Pathology Department). Field studies of resistance to late blight in four varieties. On Long Hoos III the plots were isolated from each other by kale.

(24) Potatoes, Highfield V (L. Broadbent, Plant Pathology Department). Effect of spraying against aphids with DDT on the spread of virus in the crop. Infector plants carrying leaf roll and virus Y were planted in each plot. Spraying was carried out on one, two, three or four occasions.

(25) Potatoes, Highfield IV (G. A. Salt, Plant Pathology Department). Test of dung and of two fungicides applied by two methods against skin-spot (*Oospora pustulans*).

Experiments on soil structure (J. Currie, Physics Department)

(26) Ploughed-up leys, Fosters Field, ninth year. Effects of various grass species on soil structure measured by carrots and red beet as second test crops; and by barley as third test crop. One block has been returned to perennial ryegrass, lucerne and bare fallow to start a fresh cycle.

(27) Long Hoos I, second year. Plots in preparatory period under perennial ryegrass, cocksfoot and bare fallow.

Experiment on wild oats (J. M. Thurston, Botany Department)

(28) Survival of wild oats under leys, Great Knott I, third year. Arable land infested with *Avena fatua* was put down to long ley in spring 1955. Plots have been ploughed up each year and counts of wild oat plants made.

Fertilizer experiments at Woburn

(29) Barley, Butt Close. Residues of dung and fertilizers applied to potatoes, as number (5).
(30) Barley, Butt Close. Residues of dung and fertilizers applied to sugar beet, as number (6).
(31) Barley, Lansome Field. Combine drilling nitrogenous fertilizer at various rates, as number (4).
(32) Beans, autumn and spring, Warren Field N. Test of PK and spraying, as number (11).
(33) Potatoes, Road Piece. Effect of dung, N, P, K, as number (12).
(34) Sugar beet, Road Piece. Effect of dung, N, P, K and salt, as number (13).

Pathology experiment at Woburn (G. A. Salt, Plant Pathology Department)

(35) Potatoes, Great Hill. Experiment on skin-spot with fungicides, as number (25).

Deep Cultivation Experiment, 1944–56

The results of experiments testing deep cultivation have already been summarized and discussed by E. W. Russell: namely a rotation experiment carried out at Rothamsted during the years 1934–39 * and later an extensive series of experiments on commercial farms in 1945–51.†

A long-period rotation experiment testing deep and shallow ploughing has now been concluded at Rothamsted after two complete rotations; the present note summarizes some of the main agricultural results. A more detailed examination of the yield data and chemical results will be made later.

The object of the experiment was to test whether ploughing to a much greater depth than usual led to increased yields. It was carried out on the crops of a six-course rotation: sugar beet (Kleinwanzleben), barley (Plumage Archer), 1-year hay, wheat (Yeoman), potatoes (Majestic), oats (Star), each crop being grown in turn on six blocks of land so that yields were obtained from every crop each year. The deep ploughing was repeated on the same plots each time the appropriate crops came round. Other manurial and cultivation factors, also cumulative, were included in the experiment to give the following factorial arrangement:

On main plots

Ploughed 6 inches deep *v.* ploughed 12 inches deep (for sugar beet, potatoes and wheat).

No dung *v.* dung (20 tons/acre for potatoes, 10 tons/acre for sugar beet).

No phosphate *v.* superphosphate (0·8 cwt. P_2O_5 for potatoes, 0·6 cwt. P_2O_5 for sugar beet).

* Russell, E. W. & Keen, B. A. (1941). Studies in soil cultivation. *J. agric. Sci.* **31**, 326–347.

† Russell, E. W. (1956). The effects of very deep ploughing and of subsoiling on crop yields. *J. agric. Sci.* **48**, 129–144.

No potash *v.* muriate of potash (1·0 cwt. K_2O for potatoes, 0·6 cwt. K_2O for sugar beet).

On sub-plots

Phosphate and potash, separately or together, ploughed in or in the surface soil.

For potatoes the phosphate and potash were ploughed in either 6 or 12 inches, or spread down the ridges before planting; for sugar beet the manures were ploughed in, either deep or shallow, or harrowed into the seedbed before drilling. This placement effect was measured only in the root crops.

Basal dressings of sulphate of ammonia were given to the crops as follows: sugar beet 0·8 cwt. N, potatoes 0·6 cwt. N, wheat 0·5 cwt. N, barley 0·3 cwt. N, oats 0·2 cwt. N. In addition the barley received 0·6 cwt. P_2O_5 as basic slag.

The top soil was heavy loam with flints resting on a reddish yellow clay subsoil at a depth of 12–18 inches. In places still heavier subsoil came to within 12 inches of the surface. Drainage and root penetration were good.

The deep cultivation was carried out by a single-furrow digger plough with tracklaying tractor. The previous depth of ploughing had been about 7 inches for many years; hence the deep ploughing brought up 5 or 6 inches of raw subsoil. The deep-ploughed plots were consequently much lighter in colour than the others, and sometimes needed extra surface cultivations to make a satisfactory seedbed. Although some plots were ploughed to full depth on six occasions during the course of the experiment, their characteristic appearance persisted till the end.

In spite of the unpromising appearance of the seedbeds, yields did not suffer on the plots newly ploughed to 12 inches deep, even in the first year. Thus two sugar-beet crops on fresh subsoil yielded 47·2 cwt. sugar and gave an extra 2·3 cwt. sugar for the deep ploughing. Over the whole 12-year period ploughing to ordinary depth gave 43·8 cwt. sugar, which was improved by 2·9 cwt. by deep tillage. Three potato crops grown after the first deep ploughing gave results much above the average. Wheat gave a comparison in one season only, but the yield on the new 12-inch ploughing was over 30 cwt., and the increase for deep ploughing was above average.

The yields over the 12-year period were satisfactory. Sugar beet averaged 45 cwt. sugar/acre; potatoes, though they gave light crops in two very dry summers, averaged 8·9 tons; the seeds hay at 60 cwt./acre in a single cut was very productive, while the cereals, all lying between 32 and 34 cwt./acre, could be regarded as satisfactory, since the modern higher-yielding sorts were not available when the experiment started.

The main effects of deep ploughing, dung, superphosphate and muriate of potash, and their interactions in pairs, are given for sugar beet and potatoes in Table 5; all treatments had been tested on each block on two occasions.

The main effects, which for any one factor are averaged over all combinations of the remaining three, show that deep ploughing improved the yield of sugar beet by 2·9 cwt. of sugar/acre (about

0·9 tons of washed roots). The actual value of the increase varied widely from year to year, the extremes being +12 cwt. in 1947 and −4 cwt. in 1948; in 9 years out of 12 the effect of deep ploughing was beneficial. Seedbeds tended to be much cleaner after the deep than after the shallow ploughing, and some of the benefit from deep ploughing may be attributed to this cause. This was particularly noticeable in 1947, when the beet on a clean seedbed after deep ploughing enjoyed a considerable advantage in seedling growth and

TABLE 5

Direct effects and interactions, 1944–55

Response to	Mean	Ploughing		Dung		Phosphate		Potash	
		Shallow	Deep	Absent	Present	Absent	Present	Absent	Present
		Sugar beet, total sugar cwt./acre: mean yield 45·2							
Ploughing, deep–shallow ...	2·9	—	—	3·7	2·1	2·5	3·3	3·3	2·5
Dung	6·8	7·6	6·0	—	—	7·8	5·8	8·3	5·3
Phosphate ...	1·1	0·7	1·5	2·1	0·1	—	—	1·2	1·1
Potash	2·2	2·6	1·8	3·7	0·7	2·2	2·1	—	—
		Potatoes, ware tubers tons/acre: mean yield 8·88							
Ploughing, deep–shallow ...	0·00	—	—	0·14	−0·13	0·23	−0·22	−0·11	0·12
Dung	2·66	2·80	2·52	—	—	2·55	2·76	3·60	1·72
Phosphate ...	0·62	0·85	0·40	0·52	0·73	—	—	0·46	0·79
Potash	1·53	1·41	1·64	2·47	0·59	1·37	1·69	—	—

duration of singling. The difference in weediness persisted right to the end of the inter-row cultivations. At lifting time the roots on the deeply ploughed plots were found to have very long tap roots that penetrated more deeply than the others. Dung at 10 tons/acre gave the very considerable increase of 6·8 cwt. sugar/acre or about 2 tons of roots. The results for phosphate and potash are the means of the two methods of application, and under the conditions of this experiment potash was more needed than phosphate. The mean increase of 2·2 cwt. of sugar for 1 cwt. of muriate of potash is quite considerable, and there was only one very small negative in the 12-year period. Superphosphate gave about half the effect of potash and had two small negatives. For sugar beet there are also yields for tops and plant number. Deep ploughing increased the yield of tops by 1·0 tons, dung by 1·8 tons on the average. Superphosphate had no effect, but potash increased the tops by 0·5 tons/acre. The effect of deep ploughing on plant number was to increase the population by 730 plants/acre—this in spite of the fact that in the early years at any rate the seed was sown in practically pure subsoil. Thus in the years 1944 and 1945 the land for sugar beet was ploughed deep for the first time, yet the increase in plants at harvest was 700/acre. Dung had practically no effect on the number of plants at lifting time, while the effect of fertilizers was also negligible.

Potatoes responded quite differently to deep ploughing. On the average of the twelve seasons the effect was zero; positive and negative responses, which were never more than 1½ tons, cancelled each other out. Dung at 20 tons/acre gave a large average increase of 2·66 tons/acre. In no season was the increase less than 1 ton, in 2 years it was almost 5 tons. The effect of potash was, as usual, shown strongly in potatoes, the average increase being 1·53 tons/acre. As with sugar beet, the overall effect of phosphate was rather small,

but for potatoes it was always positive, amounting in three seasons to as much as 1·5 tons/acre.

Of the two factor interactions given in Table 5, the largest are those showing the effect of dung on the responses of sugar beet to phosphate and potash; each gave good increases in sugar per acre on the plots without dung, but when 10 tons of dung was given the responses to phosphate and potash were negligible. The only other interaction of any magnitude concerned dung and ploughing depth: dung gave 1·6 cwt. of sugar/acre less if it was ploughed in deep than if it was ploughed in shallow; this effect was also shown on potatoes, but in a much smaller degree. So far as the actual effect of dung is concerned, there was no advantage to be gained from ploughing it in deeply for either crop.

On potatoes there was the usual strong negative interaction of dung and potash, for 20 tons of dung supplied almost the whole of the potash requirement of the potato crop. There was also some indication that the action of phosphate on the potato crop was greater at the 6-inch ploughing depth than at the 12-inch depth.

In Table 6 the residual effect of the treatments applied to sugar beet and potatoes are given for the three cereals and the hay crop. In the case of wheat only the deep ploughing is tested as a direct treatment.

TABLE 6

Residual effects

Mean yields, cwt./acre, and increases for deep ploughing, dung, P and K

Barley and oats, 1945–56, *hay* 1946–57

	Barley	Oats	Hay	Wheat
Mean yield	32·1	32·2	59·8	33·4
Residuals	1st year	1st year	2nd year	3rd year
Deep ploughing...	+0·2	−1·2	−0·2	+0·5 *
Dung	+1·8	+1·2	+4·0	+1·4 †
Phosphate	+0·6	+0·9	+0·9	+0·2 †
Potash	+0·6	+0·1	+1·9	+0·5 †

* Direct effect of deep ploughing 1946 and 1948–57.
† 1947–57.

On those plots that were deep ploughed for sugar beet the gain in the following barley crop and subsequently in the hay was negligible. If anything, the effect of deep ploughing for potatoes was slightly to depress the following oat crop.

Wheat measured the direct effect of deep ploughing, which was never large. The gains and losses almost cancelled out over the 11-year period. The biggest gain was +3·6 cwt. of grain/acre in 1956, while in 1948 and 1957, when the plant was clearly thinner on the deep-ploughed plots, there were losses of about the same size.

Farmyard manure gave appreciable residual effects in all crops, including wheat, which was the fourth crop after the dung had been given. The hay yields were considerably improved by dung applied to sugar beet 2 years before. The potash given to sugar beet had a smaller, but nevertheless appreciable, effect on the ley. The two factor interactions in the residual years were on the average quite small, the only consistent effect being the negative interaction be-

tween dung and muriate of potash measured in the hay crop, for the residual effect of dung was 1·9 cwt. of hay less when residual potash was also present.

The effect of ploughing in the phosphate and potash, instead of broadcasting on the surface for sugar beet or down the ridges for potatoes, was tested on half plots in conjunction with all the main plot treatments.

Table 7 summarizes the results averaging the two depths of ploughing. The table separates the effects of phosphate and potash in the presence and absence of dung.

TABLE 7

Effect of location of phosphate and/or potash, 1944–55
Ploughed in v. *in seedbed (beet) or in ridges (potatoes)*

(Mean of 6- and 12-inch ploughing depths)

	Sugar, cwt./acre		Potatoes, tons/acre	
	No dung	Dung	No dung	Dung
No phosphate, no potash... ...	39·2	47·9	6·21	9·61
Increase for:				
Phosphate and potash ploughed in	+6·3	+1·8	+2·23	+0·85
Phosphate and potash in seedbed or ridges	+5·4	−0·3	+3·70	+1·73
No potash—				
Phosphate ploughed in ...	+2·4	+1·5	+0·12	+0·72
Phosphate in seedbed or ridges	+0·7	0·0	+0·36	+0·54
No phosphate—				
Potash ploughed in	+3·6	+1·4	+1·91	+0·26
Potash in seedbed or ridges...	+2·5	+1·3	+2·45	+0·74

Phosphate and potash applied together for sugar beet gave a substantial response in sugar per acre in the absence of dung, and the result was better by 0·9 cwt. sugar if the fertilizers were ploughed in. This was also true when these fertilizers were used separately; phosphate in particular was ineffective when broadcast on the seedbed, but gave a good return when ploughed in.

Dung greatly reduced the phosphate and potash responses, but there was still an advantage in ploughing these fertilizers in. Indeed, on dunged land phosphate alone gave no result when applied in the seedbed.

The results with potatoes were quite different; in the absence of dung there was a big response to potash, either alone or with phosphate, and this response was much bigger when the fertilizer was in the ridges. Phosphate used in the absence of potash was practically ineffective, but even here the advantage lay with ridge application. Dung reduced the potash response, but the ridge application was still superior. In contrast to this, dung increased the phosphate effect, possibly because the experiment showed that potatoes responded better to phosphate when potash was also supplied.

The experiment gives some information on the effect of the depth of ploughing on the two methods of incorporating the fertilizer. In

this case the results in Table 8 are obtained as an average of the dunged and undunged plots.

When phosphate was ploughed in for the sugar-beet crop either alone or, as would almost always happen in practice, with potash also the advantage of ploughing in over broadcasting, previously shown in Table 7, was somewhat increased if the ploughing was done deeply. This effect was not found when potash was used alone.

Potatoes again behaved differently; when potash was used alone or in conjunction with phosphate the advantage of ridge application

TABLE 8

Placement effects in relation to depth of ploughing

(Mean of dung and no-dung)

Depth of ploughing	Sugar, cwt./acre		Potatoes, tons/acre	
	6 inches	12 inches	6 inches	12 inches
No phosphate, no potash... ...	42·1	45·0	7·73	8·08
Increase for:				
Phosphate and potash ploughed in	+3·7	+4·4	+1·82	+1·27
Phosphate and potash in seedbed or ridges	+2·8	+2·2	+2·67	+2·78
No potash—				
Phosphate ploughed in ...	+1·2	+2·6	+0·84	+0·01
Phosphate in seedbed or ridges	+0·2	+0·5	+0·96	−0·05
No phosphate—				
Potash ploughed in	+3·5	+1·5	+1·27	+0·91
Potash in seedbed or ridges...	+1·8	+2·1	+1·66	+1·54

over ploughing-in the fertilizer, shown in Table 7, was greater when the ploughing was deep than when it was shallow. Phosphate used without potash gave no increase at all when the ploughing was deep.

The following are some of the main conclusions on the average effects of 12-inch ploughing in this experiment:

1. Deep ploughing increased the yield of sugar beet by about 6 per cent, but not of potatoes or wheat.
2. The effect of deep ploughing was very variable from season to season, large increases and equally large depressions being occasionally recorded. The cause of these variations has not yet been found.
3. The residual effect of deep ploughing measured in cereals and hay after one, two or three seasons was negligible.
4. Raw subsoil could generally be reduced to a seedbed for sugar beet, and no loss of plant number or yield occurred. These seedbeds were often cleaner than those on shallow ploughed land.
5. Dung ploughed in deep for sugar beet had slightly less effect than if ploughed in shallow.
6. When PK was used for sugar beet it was more useful when ploughed in than in the seedbed. Deep ploughing was slightly more effective than shallow in this respect.

7. When PK was given to potatoes it was more efficient placed in the ridges than ploughed in. Deep ploughing slightly increased the relative advantage of ridge application.

Staff

G. V. Dyke was seconded for a year to Hunting Technical Services Ltd. for field experimental work in Iraq in connection with an irrigation scheme. G. F. Jarvis transferred from the Farm to the Field Experiments Section.

THE FARMS

J. R. Moffatt

Rothamsted

The weather of 1957, as of 1956, was very unusual; this had a marked effect on crop yields. Land work was somewhat behind schedule at the beginning of the year, but the main factors which gave the season such a bad start, from the agricultural point of view, were the mild, wet winter and the very few frosts. It was very difficult to obtain suitable tilths for any crop; tilths could only be obtained by constant working, mainly with disc harrows. The adverse effects of the poor seedbeds on the germination and early growth of crops was greatly accentuated by the long spring drought and the drying winds. With the exception of winter wheat and beans, which looked well throughout the year, all crops suffered, and it was not until a wet spell began towards the end of June that they looked up. Growth was then very rapid, but it was too late to undo all the damage, and many crop yields were well below average. The corn harvest was late and long, but the lifting of all root crops was carried out under good conditions. These conditions also favoured autumn land work and autumn sowing, so that by the end of the year work was well forward.

The Effect of Weather on Crops

Good progress was made with land work in the late autumn of 1956, but it was still somewhat behind schedule by the beginning of 1957. The very mild autumn of 1956 encouraged the germination of weed seeds; a second ploughing was therefore given to several areas early in 1957, when the weather was mild and fairly dry. This work was brought to an abrupt stop by heavy rain towards the end of January, and wet, mild conditions persisted until almost the end of February. By this time the land was extremely wet and the surface was badly "panned", and field work could not start until the middle of March, when good progress was made with the drilling of spring beans and cereals. However, the land was still very wet underneath, and only surface cultivations were possible. Suitable seedbeds were very difficult to obtain owing to the absence of frost tilth and to the surface pan.

Progress, throughout the latter half of March and throughout April, was slow because of the difficulty in getting suitable seedbeds. In many cases the ground had to be worked under rather unsuitable conditions in order to facilitate drying out, but from about mid-April onwards strong winds dried out the clods too rapidly, and they became very difficult to break down.

However, spring-corn drilling was completed early in April. The dry weather, with strong, cold winds, continued until about mid-May; these factors, together with the rather unkind seedbeds,

caused uneven germination and slow early growth. The sowing of kale and small grass and clover seeds was delayed by unsuitable conditions.

Rain fell about mid-May, and the spring sowings were soon completed. During the 3 months March to May the rainfall only totalled 2·97 inches, less than half the normal.

The warm, dry weather continued throughout the first 3 weeks of June, and though this suited haymaking well, most of the spring-sown crops made only slow growth. The spring-sown beans looked very backward at this stage, while the germination of root crops was uneven, and growth slow. On Barnfield, the Classical root field, germination was extremely slow, and only on the two dunged strips were the rows visible when normally the crop would be fit for singling.

The long spell of dry, warm weather was broken towards the end of June by heavy thunderstorms, and in the 4 weeks from 23 June to 20 July 3·26 inches of rain fell. Conditions soon became very sticky, and little could be done to check the rapid growth of weeds. The root crops made a spurt of growth at a time when singling was almost impossible, and a small area of mangolds had to be abandoned. In the potato crop, also, rain caused rapid growth.

The wet spell lasted, except for one or two short breaks, until about the middle of August, and only then could harvest operations really begin. Most of the crops were harvested in good condition, though towards the end of the operation spring wheat was cut with a rather high moisture content, as the weather seemed to remain permanently dull and damp. Towards the end of August there were severe gales which caused extensive shedding of the dead-ripe corn.

After a wet spell in the latter half of September, during which time the potato haulm was burnt off with BOV, the weather improved, and conditions for potato picking in October were almost ideal. Autumn ploughing got away to a good start in September, and by mid-October the winter beans and some wheat had been drilled.

November was rather mild and damp, although drier than usual. Harvesting of the mangolds and sugar beet was finished before the end of the month. The last of the winter wheat was drilled during this period. In early December there was a spell of thick fog and sharp frosts. Full advantage was taken of the dry soil conditions to cart and spread farmyard manure (F.Y.M.), and almost all the dunging was done before the ground became too wet. The ploughing of the arable ground was completed, and several fields were ploughed a second time before the end of December. By this time land work in general was farther ahead than for many years past.

Field Experiments

There was again a very full programme of field experiments, but the reasonably dry conditions, both in the autumn of 1956 and the spring of 1957, enabled the work at these two peak periods to be satisfactorily concluded, though the spring seedbeds left much to be desired.

Despite the stormy weather in July, not a great deal of lodging occurred, and the combine-harvesters were able to make a clean job on all field experiments. Nearly all the cereal plots were cut by combine-harvester, which, despite the late start, made it possible to finish harvesting in good time. This year for the first time the Classical wheat plots on Broadbalk field were cut by combine. Unfortunately some shedding took place during the severe gales just before cutting commenced, but otherwise the operation went without a hitch. Owing to rather unfavourable weather, it was spread over 5 days, and the actual time spent in the field was about the same as that taken by the binder method. Yields were taken separately from the centre cut and the two outside edges, but in future only one cut will be taken from each plot, and the position of this cut will vary from year to year. The straw was baled by a pick-up baler and weighed, but much of the chaff and fine cavings, normally removed with the sheaves, was left behind. It remains to be seen whether the use of the combine has any effect on the weed population in the field. The permanent barley plots on Hoosfield will continue to be cut by binder.

The wild oats in Broadbalk field were hand-pulled on two occasions. This has now become a routine procedure, and appears to be very necessary if a build-up of the weed is to be prevented. On Hoosfield, where this weed has been very prevalent for the past few years, drilling was again purposely delayed until 5 April in order to kill off an initial germination. All the plots were hand-pulled twice this year, and it is hoped that by continuing these two methods of control a marked improvement will soon be noticeable. Other weeds, especially coltsfoot (*Tussilago farfara*), annual sow thistle (*Sonchus arvensis*), creeping thistle (*Cirsium arvense*) and horsetails (*Equisetum arvense*), were very numerous, and the whole area was sprayed with MCPA for the first time, with excellent results.

The experimental spring bean crops had a very unhappy season because of poor seedbeds and growing weather and an extremely severe attack by bean aphids. On the other hand, the winter-sown beans did very well in this mild year. The late-sown spring beans were extremely slow to ripen. All bean plots were harvested by combine-harvester.

The mangolds and sugar beet on Barnfield had another bad year. Drilling had to be postponed, as strong winds prevented the application of fertilizers; the seedbed on that extremely heavy field was rather unkind, and the long drought which followed the drilling delayed germination. Very little growth was made until late June when heavy rain fell and the sudden spurt of growth of mangolds and weeds made it impossible to single the whole field in time. It was therefore decided that only four rows each of sugar beet and mangolds should be singled and harvested. The yield of mangolds eventually obtained was one of the highest for many years, and the roots were of excellent quality.

During the year, half of the " meadow " section of Broadbalk Wilderness was cut over seven times with a motor scythe to see what improvement this made. The cut half remained very much more green throughout the season, and botanical analysis will show what changes, if any, take place in the flora.

Cropping and Rotations

Of the total of 447 acres farmed, 66 were under permanent grass, 148 under short-term leys and clovers or lucerne, and 253 under arable crops. The latter included 83 acres of wheat, 37 acres of barley, 11 acres of oats and 30 acres of beans. Of the root area, potatoes occupied 28 acres, sugar beet 4 acres, kale and mangolds 10.

The requirements of certain cereal experiments for sites on which these crops were not grown the previous year have resulted in a further reduction in the total acreage under cereals. The bean and potato acreages have reached the limit of what can be conveniently handled, as has the area of other root crops in the absence of any seasonal labour. Any further reduction in the cereal acreage will therefore result in an increase in the acreage under temporary leys, as this is the only alternative to fallow. The lucerne–cocksfoot mixture which was sown down in 1956 has proved very successful and productive, and further mixtures of this type may be sown in the future. In view of a possible increase of this nature, a surface silo will be erected.

Crops

Wheat

The season greatly favoured the growth of winter-sown crops, but owing to pressure of other work following the very late harvest of 1956, only a small acreage was sown. The Heine's VII yielded 33 cwt. acre, but was outyielded by Leda, which yielded 36 cwt./acre. This was the first year Leda has been grown, but it topped the list in the varietal trial with a yield of 43 cwt. acre. Sixty acres of our standard spring variety, Koga II, were grown, but the season was disappointing for spring wheat, and although one small area yielded over 40 cwt. acre, most of the fields yielded under 30 cwt. acre. The Koga II was rather slow and late to ripen, and much of it had to be cut in the second week of September, despite a moisture content of about 22 per cent.

Barley

Proctor remained the principal variety, although some Herta was also grown. The spring barleys seemed to grow better throughout the season than did the spring wheats, and this is reflected in the yields, which rose to over 40 cwt. acre, with an average of about 33 cwt. acre. These yields are better than those obtained in 1956.

Oats

The acreage of this crop was reduced to 11, the variety favoured being Sun II. Of all the cereals, this crop suffered most from the unfavourable season.

Owing to pressure of work for the combines on experimental plots, the harvesting of this crop was delayed and serious shedding occurred in the gales of late August. Yields were therefore very low. Sun II was the variety mainly grown.

Beans

Only a small acreage of winter beans was sown owing to the late start of autumn operations in 1956. The crop got away to a good start, had only a very mild winter to survive and maintained growth throughout the spring drought. The aphids which were very prevalent did little damage, and spraying only increased the yield from 32 to 34 cwt./acre.

With spring beans the story was very different. They got away to a poor start and proved easy victims for the aphids. Spraying had a marked effect, and greatly increased the yield, but even the best yield was well below that of the winter variety. This is the second consecutive year that the winter have outyielded the spring beans.

Potatoes

Of the 28 acres devoted to this crop about 3 acres were under an early variety, Arran Pilot, 3 acres under Ulster Supreme and the balance of the area was planted with Majestic. Tilths, generally, were satisfactory considering the season, but planting took place rather later than usual. Early growth was very slow, but the crops shot ahead during July and developed a mass of haulm. As the weather conditions then favoured the spread of Late Blight (*Phytophthora infestans*) three preventive copper sprayings were given; these proved very effective. The haulm was burnt off in the latter half of September, but this was not as effective as usual, owing to the toughness of the haulm and the damp conditions.

The second earlies were lifted at the end of July and early in August, and yielded 7 tons/acre, all of saleable size. The lifting of the maincrops started early in October under good conditions, and yields were heavier than were anticipated. The Majestics gave a total yield of 14 tons/acre, but many of the tubers were very large and were badly cracked or split. Common Scab was rather prevalent, but there were very few blighted tubers. The Ulster Supreme variety was grown under different conditions, but yielded very well. The tubers were not numerous, but were large and had a very smooth skin. Unfortunately they lived up to their reputation as poor keepers. Although they seemed to leave the clamp in good condition, they bruised very easily during sorting and loading, and soft rots set in almost immediately.

Kale

Only about 3 acres of kale were grown, for use after the beet tops were finished. Drilling was delayed, as the ground was too dry and rough for the small seed. Following rain, a suitable seedbed was obtained and sowing was done in the second week of May. Growth in the early stages was very slow, but flea-beetle damage was prevented by a γ-BHC seed treatment. From July onwards the crop made very rapid growth, and the yield is estimated at 30 tons/acre.

Sugar beet and mangolds

Reference has already been made to the mangolds on Barnfield. The acreage of sugar beet is always kept to the minimum because of the heavy labour demands, and this year 4 acres were grown, all

experimental. There was big variation in speed of germination and early growth resulting from the dung treatments, and plots reached the singling stage at different times. Resulting from the heavy aphid infestation, there was a severe attack of sugar-beet yellow disease, and although the crop was sprayed with " Metasystox ", it was done rather too late for maximum benefit.

The crop grew rapidly during the latter part of the season, but the difference between plots remained. When lifting started soil conditions were not too good, and though they improved later, the soil remained very adhesive, and each individual beet had to be scraped clean. The mean yield of 10½ tons/acre was satisfactory for the season, as was the sugar content of over 17 per cent.

Grassland

The very mild autumn and winter of 1956–57 enabled the grassland to maintain its growth throughout the winter, and most of the cattle were outwintered on it. Spring growth started very early, and grass was plentiful by early April. As a result of this early " flush " of grass we had several tons of mangolds and about 3 acres of kale more than we needed. Sheep grazing on the grass plots of the experiments started early in April, 2 weeks earlier than usual. However, after prolific early growth the grass seemed to have spent its energy, for by mid-May the drought had so retarded growth that " keep " was becoming short, and a dressing of nitrogen was given to several areas as a stimulant. However, such growth as there was took place mainly in the formation of flowering heads, and " topping " had to be done. Rapid growth took place again during the wet spell which started towards the end of June, and was maintained throughout the autumn and early winter, giving an ample supply of grass, which lasted to the end of the year.

Most of the hay crops from the long-term leys were on the light side, but what was lacking in quantity was made up for in quality. The weather conditions were ideal, and in most cases only 2 clear days were needed between cutting and baling. The hay, being in such beautiful condition, was carted almost at once.

The lucerne–cocksfoot mixture which was grazed almost the whole of March, yielded 2 tons/acre from the first cut, taken early in June, and 33 cwt./acre from the second cut. This second cut was also made under excellent conditions early in August. No further grazing has taken place, but the sward will be grazed early in 1958.

Control of Weeds and Pests

The peculiar weather conditions of 1957 brought out some special problems of weed and pest control.

Weeds

On some land infested with couch grass (*Agropyrum repens*) two sprayings of TCA, each at 20 lb./acre, were applied. Because of the wet soil conditions the second spraying could not be given until late February in one case, and early March in another. This spraying was followed by a long period of drought. In both areas the spring corn which followed germinated satisfactorily, but the seedlings died off just before emergence.

MCPA was used on several of the corn crops, but where cleavers (*Galium aparine*) or chickweed (*Stellaria media*) were present in any quantity, DNOC or CMPP was used with satisfactory results. MCPA was also used on the "permanent" wheat section of Broadbalk field to control a heavy infestation of creeping thistle (*Cirsium arvense*).

Weeds in the bean and root crops were easily controlled by interrow cultivations in the early part of the season. However, they grew rapidly in the latter half of the season under the moist conditions, when the wet state of the ground and the height of the crops prevented any further cultivations.

Pests

The year was fairly free from severe infestation by pests, and in all cases damage was reduced by spraying. Eggs of the mangold fly (*Pegomyia betae*) were present in large numbers on sugar-beet and mangold leaves; here damage was prevented by spraying with miscible DDT. Aphids were present in very large numbers, and caused a severe attack of sugar-beet yellows, which should have been minimized by an earlier spraying.

The very heavy aphid (*Aphis fabae*) infestation caused little damage to winter beans or to spring beans where spraying was done sufficiently early. Where spraying was delayed some loss of yield occurred, and on plots where no spraying was given yields ranged from 0 to 5 cwt./acre.

Livestock

Cattle

In 1956 the decision was made to qualify for the Attested Herds Scheme during 1957. As the preliminary tuberculin test showed several reactors amongst the fattening cattle, it was decided to finish these off as early as possible and to delay the purchase of fresh stock until all the reactors were sold. Owing to the ample supply of winter grass and the mild weather, the covered yards were not used at all in 1956–57, but the reactors were segregated and fattened off in an open yard.

The purchase of fresh store cattle was therefore delayed until the early months of 1957, by which time prices had risen steeply. However, some 40 Hereford, 20 Galloway cross and 13 Aberdeen Angus cross cattle, all attested, were purchased and a further 22 Herefords were transferred from Woburn later in the year. Most of these were sold fat from the grass during the summer and autumn, but the remainder were brought into yards for finishing during the winter of 1957–58. Altogether 88 cattle were sold fat during the year. They were all sold within the 1½–2-year age range, and mostly at weights between 8 and 10 cwt.

The herd had three clear tuberculin tests during the year, and became attested in September.

Some fresh young stock was purchased in December, and more will be purchased early in 1958. These will be used to graze off the lucerne–cocksfoot sward and the rough grass on some of the outlying fields.

Sheep

The rather old Scotch Half-bred ewe flock was again mated to Suffolk rams. The lambing season was very successful in that lambs were plentiful, the ewes had plenty of milk, losses were low and weather conditions were good. There were 122 lambs from the 66 ewes put with the rams, a lambing percentage of 182, the highest for several years. Losses from Pulpy Kidney disease began to occur; the flock was inoculated immediately, and later vaccinated against the disease.

Twenty of the lambs have been sold fat, the remainder being retained for grazing on field plots here and at Woburn in 1958.

Thirty-four young home-bred ewes from the 1956 lamb crop have been retained for breeding and were put to the tup with the remainder of the old ewes in October. It is proposed to sell them with their lambs in the spring.

Fortunately no sheep-worrying has been observed this year.

Implements

The purchase of new implements was restricted, as much of the money available was spent on equipment needed for the grain-drying and storage plant. However, a few items were purchased, including a reversible plough and a fertilizer distributor for use on experimental plots. One of the old vaporizing-oil tractors was exchanged for the latest diesel-engined model.

Grain Drying and Storage Plant

The plant, consisting of four radially ventilated drying bins and eight square galvanized storage bins, was completed during the year and was put into operation for the first time for the 1957 harvest. It performed very well, and was about adequate to deal with the output of the two 10-foot combine-harvesters, one of which spends most of its time cutting the produce of experimental plots. No pre-cleaning was done, as this required an extra elevator, which it was hoped would not be needed. However, in the light of our experience in 1957 it has been decided to install this elevator during the year so that pre-cleaning can be carried out when necessary.

The relative humidity was constantly recorded so that the minimum amount of heat was used. As the volume of grain to be dried diminished towards the end of harvest, drying was only done when the relative humidity was such that no heat was required.

The fifty-hole platform drier was moved and re-erected adjoining the new plant so that the one fan and heater can be used for either the drying silos or the platform drier. On re-erection the platform was arranged with holes in banks of twelve so that any multiple of this number of sacks, up to forty-eight, can be dried at once. This greatly facilitates the drying of small quantities of grain from experimental field plots.

Estate Work

Following the inspection of the woodlands in 1956 by the Forestry Commission, a lot of tree thinning was carried out during the early

months of 1957, but much more remains to be done before appreciable replanting can be done. It is hoped to make some further progress with this work during the winter of 1957–58.

Owing to the pressure of other work, no progress was made in 1957 with the clearing of the derelict orchard in Whittlocks field which was purchased in 1955. However, it is planned to push ahead with this work early in January 1958, and it is hoped to clear the field before the rush of spring work commences.

Staff

G. F. Jarvis transferred from the post of Recorder to the Field Experiments Section in December 1957. The vacant post has not yet been filled.

Woburn

The work of the Woburn Farm is directed and managed by the staff of the Rothamsted Farm. The field experiments are planned by the Field Plots Committee, while the day-to-day planning is done by the bailiff at Woburn.

1957 was a rather disappointing year for cereals, nearly all of which were spring sown. These felt the full effect of the spring drought on the light Woburn soil. On the other hand, potatoes and sugar beet, after a slow start, developed into good crops.

The Effect of Weather on Crops

Despite the delayed start of field work in the autumn of 1956, following upon the very late harvest, this work was reasonably well forward by the beginning of 1957. Good progress was made in January, but heavy rain at the end of the month put a stop to further work. The wet conditions prevented much land work in February, and not until the end of the month could the ploughing be finished. The winter of 1956–57 was remarkable for its mildness. Except for a brief spell in December 1956, there were remarkably few frosts, none of any severity, and no snow at all.

After a false start early in March, the preparation of seedbeds for spring cereals commenced about the middle of the month, and drilling followed immediately. As the dry weather continued it became increasingly difficult to get suitable seedbeds for other crops, and sowings were delayed. However, on the lighter soil at Woburn the difficulties were not so pronounced as on the much heavier soil at Rothamsted. Only 0·2 inch of rain fell in April, compared with the average of 1·5 inch. The drought continued well into May, and the sowing of small seeds had to await rain, which fell about the middle of the month. During the drought the surface of the soil on the heavy-land field in which beans were growing set hard and huge cracks appeared, making inter-row cultivations impossible. The total rainfall for the 3 months April to June totalled 2·91 inches, compared with the average of 5·18 inches.

Except for a fairly heavy fall of rain early in June, the weather remained mainly hot and dry. The effect of this was apparent mainly on the grassland, where growth ceased, on the early potatoes

and on spring beans on light soil. These wilted and lost some of their leaves prematurely. Growth of all the other crops was retarded, although they looked quite well.

There was a sudden change in the weather towards the end of June, and the wet spell lasted most of July. This transformed the appearance of all crops and grassland, and rapid growth took place.

The start of harvest was delayed by bad weather until the middle of August, and the operation lasted about a month.

The latter half of September was wet, but a fine spell of weather in the first half of October enabled good progress to be made with the potato harvest. After a stormy start, November developed into a mostly cloudy but dry month, and good progress was made with the lifting of the sugar-beet crop. Early December brought a spell of frosts and fogs, and during this time the harvesting of the sugar beet was completed. The weather later deteriorated, and not a great deal of land work was possible, so that by the end of the year quite a lot of ploughing remained to be done.

Cropping

Of the 127 acres farmed, 16 acres were under wheat, 29 under barley, 5 under oats, 8 under beans, 22 under potatoes and 5 under sugar beet. There were smaller acreages of kale, lucerne and turnips. Four acres were sown down under a nurse crop to a short-term ley.

Beans were grown again this year to lengthen the interval between white-straw crops and so reduce the risk of disease. Oats were included again after an interval of several years as an alternative to wheat and barley. The acreage of potatoes was limited by the presence of potato-root eelworm in several fields, and sugar beet by the absence of seasonal labour.

General Notes on Crops

Wheat

This is not a very satisfactory crop at Woburn, and, because of the risk of bird damage during the autumn, very little winter wheat was sown. The Koga II spring wheat was sown in good time, and, despite the adverse weather conditions, maintained reasonable growth during the season. However, the crops were rather thin, and estimated yields are about 25 cwt./acre.

Barley

Both Herta and Procter varieties were grown. Germination was reasonably good, but subsequent growth was uneven, and the crops had a patchy appearance early in the season. Some quite severe yellowing occurred in patches—possibly due to potash deficiency—and much of the barley also developed a rather peculiar prostrate habit, probably connected with the drought. As the season advanced the appearance of the crop improved, and it came into ear rather earlier than usual. However, ear emergence was very uneven, and towards harvest, when most of the ears were ripening, some were still emerging. Even at harvest there was

quite a proportion of green ears which made harvesting more difficult, and spoilt the sample of grain. Yields are expected to be about 26 cwt./acre.

Oats

This crop was grown for the first time for many years. The crop was sown early and looked quite promising in the early summer, but later developed symptoms of severe cereal-root eelworm. This was confirmed and the crop was almost a complete failure.

Beans

This was also a disappointing crop. It got away to a good start, but by mid-April the heavy land had set so hard that inter-row cultivations were impossible. The soil then cracked badly, yet weeds continued to grow. Hoeings were attempted in the middle of May after rain had fallen, but by this time the weeds were so big that they drove up in front of the hoes, and the crop was so forward that some damage was unavoidable. At this time the spring beans on the light soil of the Irrigation experiment looked exceptionally well, and the ground was clean.

During June neither the winter nor the spring strains made the growth that was expected, and the latter strain on the light land suffered from lack of moisture, and wilted badly. Many of the lower leaves had dropped off by mid-June, and many of the flowers seemed to wither up and fall, without having set seed.

There was an early infestation of bean aphids (*Aphis fabae*), heavy on the winter strain but much heavier on the spring strain. All crops were sprayed with " Metasystox " early in June, and while this gave an appreciable benefit to the winter crop, it was applied too late to be of any great benefit to the spring strains. Yields were therefore low, as was expected.

Potatoes

The planting of both early and maincrop varieties was delayed by unsuitable conditions, and the latter were not finished until well into May. By this time the early varieties were well through the ground, and some slight frost damage occurred. Growth was very slow during May and June, and rooks and jackdaws did some damage to the young tubers of the earlies, even after earthing up had been done. One area of earlies was sprayed with dieldrin in the hope that this would deter the birds. Lifting was done in the first half of July, and the average yield was about 4 tons/acre.

The maincrop varieties, which consisted mainly of King Edwards, grew rapidly during the damp weather of July, August and early September. Three preventive sprayings were given against Late Blight (*Phytophthora infestans*), and these succeeded in keeping the haulm green until it was burnt off in the latter half of September. Yields were very satisfactory, the Majestic and Ulster Supreme yielding between 13 and 14 tons/acre, and the King Edwards about 9 tons/acre. The tubers of the two former varieties were large and somewhat mis-shapen, but they were not badly split, and there was little evidence of blight on them. The size of the King Edwards

was almost ideal, but as there was more blight in evidence, they are being disposed of before secondary rots set in.

The weather conditions were excellent for most of the lifting operations, though they deteriorated towards the end.

Sugar beet

This crop was drilled by mid-April in reasonably good seedbeds. Germination and early growth were as good as could be expected under the conditions prevailing, but singling was somewhat delayed by the rather backward state of the plant. A threatened attack by the Mangold Fly (*Pegomyia betae*) was averted by spraying with miscible DDT, and later an attempt was made to prevent the spread of sugar-beet yellows disease by spraying against the aphids with " Metasystox ". However, this was only partially successful, and the disease became widespread, though not severe.

The crop made very rapid growth in the latter half of the summer, and lifting commenced as soon as potato lifting was finished. The roots were of good size and shape, and yields averaged about 17 tons of beet, with a sugar content of almost 18 per cent. The yield per acre of sugar was therefore about 62 cwt.

Market-garden crops

The lifting of the leeks was delayed, owing to pressure of spring drilling operations, until late March, and then liftings took place weekly until early May. The individual plants were of good size, and yields were well above the average. Unfortunately, however, there was little demand for them. The leeks planted out in late July had an excellent start, and good growth has been maintained.

The red beet on the market-garden experiment grew well despite the long drought, and, after thinning, had a better plant than for some years. This was reflected in the average yield, which was the highest for many years.

The carrots grown as a test crop on the ley–arable experiment were sown late, owing to the difficulty in obtaining a suitable seedbed. Sowing took place after rain, but germination was poor and slow, and the young plants just died off in the drought. They were replaced by white turnips, which grew vigorously and yielded well.

Grassland

The grass made very good growth in the early spring, but this had slowed down by mid-April. By mid-May growth had stopped, and thereafter no growth took place until rain fell towards the end of June. During this period there was insufficient " keep " for the number of livestock there. An application of nitrogen had no effect, as there was no rain to wash it in. During July, however, the grass grew very vigorously and provided an ample supply for the stock. Growth was maintained until the end of the year.

Only a small area was shut for hay owing to the shortage of grass in the late spring. However, this gave quite a good yield of hay, which was made and carted in lovely condition.

Field Experiments

The classical wheat and barley plots were fallowed again in 1957, to eliminate the twitch *Holcus mollis* from the wheat ground and *Agrostis gigantea* from the barley ground. The season favoured the cleaning operations, and it is to be hoped that the land is now clear of these weeds. A further supplementary liming was also given to even out the pH values.

For the 1957–58 season the plots are being divided into strips giving a comparison of winter and spring wheats, and winter and spring barleys. This should provide the answer as to whether the crop failures in past years can be ascribed to acidity, weed competition or some other form of crop sickness, as has been suggested.

Unfortunately the two winter-sown crops were drilled rather late, and have already been damaged by birds. It is probable that bird damage will occur on the early ripening winter barley just before harvest.

Some of the long-term experiments were modified. In the irrigation experiment spring wheat replaced barley as the cereal crop, and spring beans were introduced into the rotation. These proved a remarkably interesting crop to grow on light land, as irrigation doubled the yield, whereas spraying against bean aphis (*Aphis fabae*) had little effect. For the sugar beet, the manurial dressings, which were low according to modern practice, were increased by half.

A minor modification to the green manuring experiment was that the basal fertilizers were applied by drill, instead of by hand.

On the ley–arable experiment the treatment crop of carrots failed owing to the drought, and was replaced by white turnips. Stem eelworm of lucerne was found to be the cause of the poor colour and stunted growth of this crop, which were so noticeable in the spring. All infected plots were ploughed up, and if necessary in future, the crop will be changed to sainfoin.

In the six-course rotation experiment the trifolium, which has replaced the undersown clover, was sown in the autumn of 1957 for the 1958 crop, in an attempt to get better yields. Previously this seed has been sown in the spring of the harvest year.

The number of annual cereal plots has increased rapidly over the past few years. Wherever possible these have been harvested by a combine-harvester sent from Rothamsted, as was done this year. Owing to the increasing number of plots at Rothamsted, this will no longer be possible, and it is hoped to have a suitable machine at Woburn for the 1958 harvest.

In 1957 on three cereal experiments the crop failed to come through the ground. Soil tilths were satisfactory and the seed germinated well enough, but the shoots died off just before they emerged. This can only be ascribed to a late spraying with TCA against twitch, applied at 20 lb./acre a month before sowing. Had weather conditions been more normal, this damage might not have occurred.

Livestock

Cattle

A small number of Galloway-cross cattle were purchased in the autumn of 1956. These were yarded during the winter, and most

of them sold fat in early spring. A bunch of Hereford cattle were bought in early spring, and did well on the abundant grass. However, as the drought increased in severity and the grassland became less productive, there was insufficient grass, and 10 cattle were transferred to Rothamsted. The remaining cattle thrived on the abundant grass in late summer. They, too, were transferred to Rothamsted in the late autumn, to facilitate their marketing and to make room for younger stock.

The herd had two clear tuberculin tests during the year, and so qualified for the Attested Herds Scheme.

Pigs

The improvements to the housing for pigs, started in 1956, were completed during the year by the addition of four farrowing pens.

Several of the older sows, and those with unsatisfactory records, were disposed of, and 7 in-pig Large White gilts, and a boar, were purchased from well-known herds. In addition, 9 home-bred gilts and 1 boar were kept. The breeding herd now totals 20 sows, which is about the size aimed at.

The use of infra-red heat, the creep-feeding of pelleted food and the use of antibiotics in conjunction with the improved housing, have all played their part in improving the size and weight of litters. However, there is still considerable room for improvement.

During the year 163 pigs were sold, mainly for bacon, but grading returns were disappointing.

WOBURN EXPERIMENTAL STATION

C. A. THOROLD

Dr. H. H. Mann retired from his appointment as Assistant Director, and his duties were assumed by C. A. Thorold, as Officer in Charge, Woburn Experimental Station. A. Peacock, laboratory assistant, resigned in October.

In the first three months of the year, the weather was relatively mild, but April and May were cold, dry and deficient in sunshine, as shown in Table 1 below. Conditions were better during June and the first week of July; in August and September the weather was generally cool, wet and cloudy, so that some difficulty was experienced in the satisfactory harvesting of crops.

TABLE 1

Monthly mean temperatures (means of maximum and minimum), total rainfall and daily means of bright sunshine for months of April to September 1957, *with departures from long-period means in brackets*

Month	Mean temperature, °F.	Rainfall, inches	Bright sunshine (daily mean), hours
April	47·1 (+0·7)	0·20 (−1·34)	4·81 (−0·10)
May...	50·0 (−2·0)	1·34 (−0·60)	5·70 (−0·37)
June	59·4 (+1·9)	2·13 (+0·17)	9·21 (+2·58)
July	62·1 (+0·7)	2·52 (+0·29)	4·52 (−1·51)
August	59·7 (−1·0)	3·54 (+1·23)	4·45 (−1·40)
September	54·9 (−1·8)	2·82 (+1·04)	3·39 (−1·26)

FIELD EXPERIMENTS

Permanent wheat and barley

Following a period of fallow, it was decided that these areas should be cropped again in 1957–58. Since it was of interest to observe how wheat cropped on the barley land and barley on the wheat land, the Field Plots Committee decided that on all the full-sized plots there should be a comparison of winter wheat *v.* winter barley *v.* spring wheat *v.* spring barley. In the smaller plots of only half the standard width the comparison should be restricted to winter wheat *v.* spring barley. In accordance with these arrangements, both winter wheat (Squareheads' Master) and winter barley (Pioneer) were sown in the permanent wheat and barley areas, in the autumn of 1957. The appropriate strips of spring wheat and spring barley will be sown in both areas in the spring of 1958.

Six-course rotation experiment

The undersown red clover failed in the winter of 1955, and crimson clover was sown in March 1956. There was again a spring

sowing in 1957, in accordance with a decision of the Field Plots Committee that spring-sown crimson clover should be substituted for under-sown red clover in this experiment.

The root crops (potatoes and sugar beet) yielded relatively well, but cereal crop yields were poor in 1957. The mean yield of sugar-beet roots was over 14 tons/acre, although the sugar percentage was slightly smaller (17·5 per cent) in 1957 as compared with 1956 (18·1 per cent), the mean yield of total sugar per acre (49·8 cwt.) was greater than the corresponding figure in 1956 (38·9 cwt.). The mean yields of potatoes, as total tubers per acre, were 12·2 tons (1957) and 10·9 tons (1956). Amongst the cereal crops, rye did fairly well, giving a mean yield of 24·8 cwt. grain and 28·9 cwt. straw/acre. Yeoman wheat was very poor (10·0 cwt. grain/acre), some of the plots being badly damaged by birds. In 1957 the mean yield of barley grain was 28·4 cwt./acre, as compared with 34·0 cwt. in 1956.

Green manuring experiment

There are sequences of barley with undersown green manures, followed by early potatoes with catch-crop green manures. The main theme is the evaluation of undersown green-manure crops (with and without the return of cereal straw) and of catch-crop green manures after early potatoes.

As in the Market Garden experiment referred to below, early potato yields were relatively small, being only 3 tons/acre, while the mean yield of barley grain was 19·4 cwt./acre.

Ley and arable rotations experiment

The results from this experiment have been summarized and discussed by H. H. Mann and D. A. Boyd in a paper to be published in the *J. agric. Sci.* This experiment was started in 1938, to determine whether the presence of a continuously growing crop (either a clover and grass ley, or a hayed crop of lucerne) would leave the land in a more fertile condition than if it were under continued arable cropping, with adequate manuring. At the time the experiment began there was little information on the subject; the Woburn conditions, with light but deep soil, seemed well suited for such a test. Accordingly an experiment was laid out in which the fertility after 3 years of a grazed grass and clover ley, or a 3 years' crop of lucerne cut for hay each year, was contrasted with that obtained after 3 years of arable cropping (potatoes followed by wheat or rye) succeeded by either sugar beet or a hay crop. The treatments were identical in other respects, except that the nitrogenous dressings were suited to the crops grown. The results appear to provide a verdict in favour of ley farming, the land being apparently more fertile after 3 years ley, whether this is grazed grass and clover or hayed lucerne, as contrasted with a continuous arable rotation. The advantage seems to persist into the second crop (barley) after the leys have been buried. Other considerations which have been taken into account in connection with this experiment are the effect of season on the general result, and the extent to which the amount of nitrogen in the soil has been affected by the various treatments.

Market Garden experiment

The theme of this experiment is the modification of a farm soil towards a condition better suited for market-garden crops, through dressings of bulky organic manures, with and without the use of inorganic nitrogen.

Leeks were planted in August 1956 and harvested in the period 28 March to 2 May. The mean yield for all plots was 4·5 tons/acre, which compares favourably with the yield of 2·5 tons obtained in 1956. The early potatoes gave a relatively poor yield of 4·6 tons, as compared with 8·1 tons in 1956. However, it should be noted that the planting date in 1956 was 23 March, whereas in 1957 it was 1 April. It seems likely that early development in 1957 was adversely affected by the cold and dry spell which occurred in April and May. On the other hand, Globe beet yielded relatively well at 8·4 tons/acre of saleable bulbs. The beet seed had been drilled on 15 May; consequently development was mainly under relatively good growing conditions in June and July. Globe beet had given a smaller yield (6·3 tons) in 1956, when the seed was sown on 28 April. The treatment combination which gave the largest yield of beet bulbs in 1957 (13·8 tons) was dung at 20 tons/acre, plus inorganic nitrogen (" Nitro-chalk ") at 0·3 cwt./acre. In the absence of either organic or inorganic nitrogen applications, the yield was only 2·3 tons/acre. Apart from quite evident beneficial effects from nitrogen applications to the crops, there are certain obvious effects on the weed flora (H. H. Mann, " Weed herbage of slightly acid arable soils as affected by manuring " (*J. Ecol.* **45** (1957), 149–156)).

Irrigation experiment

Beans were substituted for potatoes in 1957, because potato-root eelworms had been found in the experiment area. The Cut Grass block, which was planted with cocksfoot (S 37) in 1954, continued

TABLE 2

Weights of dry grass (G) and of nitrogen (N) removed (cwt./acre) at each cutting, with and without irrigation, and at different rates of nitrogen application, in 1957

Date of cut	Level of nitrogen application							
	Without irrigation				With irrigation			
	0·30 cwt.		0·60 cwt.		0·30 cwt.		0·60 cwt.	
	G	N	G	N	G	N	G	N
23 April ...	8·4	0·2	15·5	0·5	9·0	0·3	16·0	0·5
24 May ...	12·4	0·3	15·1	0·5	15·7	0·4	17·8	0·6
19 June ...	2·1	0·1	3·4	0·2	11·5	0·3	15·9	0·5
12 July ...	6·3	0·3	7·8	0·4	14·8	0·5	17·9	0·7
29 July ...	11·6	0·4	14·3	0·7	7·8	0·3	7·9	0·4
16 Aug. ...	4·6	0·2	4·5	0·2	5·4	0·2	5·3	0·3
10 Sept. ...	9·6	0·4	12·0	0·6	8·3	0·4	9·4	0·4
5 Nov. ...	8·0	0·3	11·7	0·5	9·0	0·4	11·0	0·5
Total ...	63·0	2·2	84·3	3·6	81·	2·8	101·2	3·9

There were eight nitrogen applications, at 0·30- and at 0·60-cwt. levels, respectively, totalling 2·4 and 4·8 cwt. nitrogen/acre.

Irrigation amounted to 1·65 inches in May, 2·25 inches in June, and 1·0 inch in July (total 4·90 inches).

to be virtually free of other grasses and legumes. Interest therefore attaches to the amount of nitrogen in the cut grass. T. W. Barnes has again been responsible for the systematic irrigation carried out in this experiment. He has determined the nitrogen content of samples of grass taken at each cutting, as was also done in 1956. The percentages of nitrogen reflect the levels of " Nitro-Chalk " applied. In 1956 this fertilizer was given at two levels, equivalent to 0·15 and 0·30 cwt. nitrogen/acre, respectively. Then the mean nitrogen percentage of the cut grass at the lower level of application was 2·39 per cent, and at the higher level 2·71 per cent. In 1957 each application was double that of 1956 (0·30 cwt. *v.* 0·60 cwt. nitrogen/acre), and the respective mean nitrogen percentages of the cut grass were 3·59 and 4·19 per cent. It should be noted that " Nitro-Chalk " was given in March of both years, and subsequently after each cut except the last—a total of six applications in 1956 as against eight applications in 1957. The yields of grass, expressed as dry matter, and the calculated amounts of nitrogen removed by the crop in 1957 are set out in Table 2 below.

Bean experiment

In an experiment carried out in Warren Field, autumn-sown beans (S.Q. Giant) and spring-sown beans (Albyn Tick) were grown in adjacent plots. The mean for all autumn-sown plots was 20·1 cwt./acre, whilst the spring-sown beans gave a relatively poor yield of 8·3 cwt./acre. In previous years, when spring-sown beans were grown at Woburn, higher yields were obtained (16·7 cwt. in 1956 and 17·8 cwt. in 1953).

Jerusalem artichoke

Small plots of " Topine " and of a variety originally introduced from Russia were grown in 1957 for multiplication purposes.

Eelworm occurrences

Sugar beet has replaced potatoes as the first test crop in the Ley and Arable Rotations experiment, through the incidence there of potato-root eelworm (*Heterodera rostochiensis*). The Nematology Department reported the presence of lucerne-stem eelworms (*Ditylenchus dipsaci*) in four lucerne plots of the same experiment. In two of these plots the lucerne was in its third year and due to be ploughed, but the two other affected plots were ploughed prematurely (2nd year lucerne) as a control measure. Cereal-root eelworms (*Heterodera major*) were found on oats in Butt Furlong, where there had been eight cereal crops in the last 10 years. This area will be used by the Nematology Department for long-period field experiments.

Buried samples of aluminium alloys

On behalf of the British Non-Ferrous Metals Research Association, arrangements had been made in 1952 for aluminium-alloy specimens to be buried in Lansome Piece. Some of the buried specimens had been dug up in 1954. Mr. Hector S. Campbell, Head of the Corrosion Section, British Non-Ferrous Metals Research

Association, visited the Woburn Experimental Station on 4 September and removed further specimens, leaving others which are due to be dug in 1962.

Laboratory

The laboratory has been renovated and redecorated, and the glasshouse and cage reconditioned. Major improvements are the installation of Calor Gas supply, better darkroom facilities and thermostatically controlled electric heating. In spite of interruptions through these operations, T. W. Barnes carried out the normal programme of laboratory work in connection with the field experiments, but there was little opportunity for novel investigations.

The writer is greatly indebted to Dr. H. H. Mann for much assistance and advice. The Woburn Experimental Station continues to benefit in numerous ways through his unique knowledge of the experiments; his participation is greatly appreciated.

TROPICAL SOILS

H. Greene

This note deals with soil work in territories receiving support from Colonial Development and Welfare Funds. During 1957 Ghana and the Federation of Malaya achieved independence: it is perhaps appropriate to offer congratulations and good wishes to the soil men who now have increased responsibilities in those two territories.

Dr. R. Glentworth of the Macaulay Institute has made a preliminary report on the soils of Hong Kong: he describes a sequence of paddy soils differing in drainage of their subsoils. Under his direction further studies of the soils of Hong Kong are being made by C. J. Grant. Under recent leadership of Mr. A. C. S. Wright of the Soil Bureau of New Zealand, good progress has been made in soil survey of the Fijian Islands: N. G. Cassidy and I. W. Twyford are responsible for much of the supporting analytical work. In North Borneo T. R. Paton has surveyed the heavily forested Apas–Balung region, which includes valuable recent volcanic soils and also infertile strongly weathered soils. On the other side of North Borneo A. W. Allen has surveyed the soils, and R. H. Forster the agricultural practices of the Keningau plain, a terraced valley with soils ranging from fertile alluvium to infertile podsols. A report by C. A. H. Hodge on some soils of British Somaliland has been prepared for circulation. A revised map showing soil associations of Tanganyika is contained in the new edition of the *Atlas of Tanganyika*. It represents the views of W. E. Calton. A soil map of the copper belt of Northern Rhodesia has been published together with a report which includes field observations by A. O. Ballantyne and valuable analyses by J. B. M. Vogt. The upland soils have a very low content of magnesium and other plant nutrients. About 300 miles to the east of the copper belt there is the Ngoni " devasted area ", of which M. J. S. W. Priestly and P. Greening have made a land-utilization survey. Their interesting report published in November 1956 advocates, as others have done, changing from communal to individual ownership of land. A contrary view was persuasively presented by Sir Gerard Clauson in *Communal Land Tenure* published by F.A.O. in 1953. Some at least of the Ngoni soils are much more fertile than those of the copper belt.

In the adjacent territory of Nyasaland G. Jackson has carried out a reconnaissance of lands in an area north of Blantyre and has made land-use surveys of smaller areas adjoining the brackish Lake Chilwa and near Nkata Bay on Lake Nyasa. The Nyasaland Government has a report on soils of the Elephant Marsh which is flooded by the Shire river: analyses by C. V. Cutting show that the soils would be suitable for sugar cane if water control were established. G. Murdoch has continued soil survey in Swaziland.

Under direction of E. M. Chenery rapid progress is being made in the soil survey of Uganda. The aim is to complete a reconnaissance

soil map of Uganda by July 1959. J. F. Harrop, C. D. Ollier and S. A. Radwanski undertake the field work, which is supported by soil-fertility studies and analysis. Soil surveyors are at work in Western and Northern Nigeria but not yet in the Eastern region. J. C. Chisnall has begun a survey of seasonally flooded inland areas of Sierra Leone. M. Brunt of the Directorate of Oversea Surveys has carried out a land-use survey including paddy fields and upland areas along the River Gambia.

D. M. Lang has completed his field work in the soil survey of Malta: according to D. A. Osmond the soils are calcareous, some resembling those of Cyprus and falling conveniently into Kubiena's system of classification. The coastal soils of British Guiana have been surveyed in part by Messrs. D. Crocker and C. H. Simonson provided by the International Co-operation Administration; under the direction of T. A. Jones of the Regional Research Centre for the West Indies a reconnaissance survey of the Rupununi Savannah has been completed and additional surveys are being undertaken elsewhere in British Guiana. J. Stark has been seconded to this team. There is now an evident need for agronomists to discover how the various soils can best be used. Good progress has been made in the soil survey of Jamaica.

In Fiji pot tests and field trials supplement the soil survey; large responses have been obtained with nitrogen, phosphorus and potassium fertilizers but not yet with minor nutrients or lime. One problem is to find crops to replace sugar cane when the Rewa mill closes down. Minor nutrients are of interest in East Africa. E. M. Chenery, adapting pot techniques originated at Long Ashton, has observed boron deficiency in tea; he finds the most common deficiencies in Uganda are nitrogen, phosphorus and sulphur. W. E. Calton and J. W. Vail have prevented die-back in wattle by spraying with boron. This was at Njombe, Tanganyika Territory. In pasture research at Kitale, Kenya, E. D. Bumpus and his colleagues have been finding that grass and legume mixtures respond strongly to the sulphur of gypsum; indications of a response to magnesium have been obtained in field trials with Kenya white clover and with lucerne. Local variation is high, however, and these observations await confirmation.

Water is the most important of the plant nutrients: H. C. Pereira of the East African Agriculture and Forestry Research Organisation is leading co-operative studies relating plant cover and stream flow in East Africa. H. L. Manning of the Empire Cotton Growing Corporation has made a study of rainfall probability in relation to Uganda agriculture. He demonstrates the importance of the seasonal pattern of rainfall. J. B. D. Robinson has obtained good growth of maize, beans and pineapple on camber beds constructed in ill-drained hollows of the coffee research station, Ruiru, Kenya. H. F. Birch of the East African Agriculture and Forestry Research Organisation has devised a respirometer which has enabled him to demonstrate fairly uniform decomposition of organic matter with formation of nitrate when soil is repeatedly wetted and dried. These laboratory tests throw light on changes in the field at the beginning of the rain season and may explain why early sowing is so important.

In the Lake Province of Tanganyika J. E. Peat and his associates

of the Empire Cotton Growing Corporation have firmly established for cotton and millet the value and long-lasting residual effects of cattle manure and of double superphosphate. When these are applied there is also a response to top-dressed nitrogen. Tie-ridging, which retains rain-water, is notably beneficial also. Numerous field experiments in Nyasaland continue to show a general and profitable response to nitrogenous fertilizer. This is the case with various crops, including tea; young tea has benefited from the sulphur in fertilizers; tung near Zomba responded to nitrogen but failed to give an expected response to zinc. In the less-mountainous parts of Basutoland A. C. Venn continues to find a marked response of maize and wheat to small applications of phosphate, but consistent responses to nitrogen have not yet been obtained. No deficiency of minor nutrients has been observed. For rice in Zanzibar G. E. Tidbury finds the most profitable dressing is 2 cwt./acre of sulphate of ammonia plus 3 cwt./acre of single superphosphate.

H. Irving has summarized fertilizer studies (1947–51) carried out on acid sandy soils of the Eastern Region, Nigeria. With yams nitrogen and phosphorus gave fairly consistent gains: with intercrops of melon and maize there were responses to nitrogen: cassava intercrop showed some response to nitrogen and potassium. Rice on inland swamps responded well to superphosphate, as is the case in Sierra Leone also. There the field experiments of C. J. Piggott have confirmed that groundnuts at Njala require calcium and also phosphorus, potassium and magnesium. He is also using pot tests and the subtractive technique which R. A. Webb brought to the Gambia from Long Ashton. Using small Kraft bags containing soil in which wheat was sown, G. Murdoch in Swaziland demonstrated clear differences between soils and a general response to nitrogen and phosphorus. At the West African Rice Research Station at Rokupr, Sierra Leone, T. E. Tomlinson examined soils of mangrove swamps. He found that those containing fibrous residues are likely to become extremely acid after exposure to air, and should not be chosen for empoldering: rice seedings are severely damaged at pH 4 or less. Observations by M. G. R. Hart suggest that the acidity is due to bacterial oxidation of elemental sulphur. P. W. Arnold has returned to Rothamsted after one year's secondment to the West African Cocoa Research Institute. He observed that in some fertilizer experiments the trees and soils were damaged by too heavy and too localized application of fertilizer. Good results are now being obtained in revised experiments carried out by R. K. Cunningham. Field experiments with groundnuts in the Gambia have not yet shown a striking response to minor nutrients, but have confirmed a marked deficiency of the major nutrients. In Cyprus P. A. Loizides has recorded prolonged residual responses to basic slag and to farmyard manure applied to calcareous alluvial clay loam. At the Imperial College of Tropical Agriculture, Trinidad, T. A. Jones, G. Havord and G. K. Maliphant have evolved a promising technique for studying uptake of nutrients by excised cocoa roots.

In the autumn of 1957 H. Greene visited Swaziland, Southern Rhodesia, Nyasaland, Northern Rhodesia, Kenya, Tanganyika, Uganda, the Belgian Congo, Pakistan and Malta. In the Congo he

attended discussions regarding the work of the Inter-African Soil Bureau, located in Paris, and of the Inter-African Pedological Service, located at Yangambi in the Congo. In Pakistan Greene attended meetings organized by the Food and Agriculture Council of Pakistan and by the United Nations Educational Scientific and Cultural Organisation with a view to Arid Zone research. On this occasion there was a symposium on soil erosion and its control. E. W. Russell was an invited participant in the symposium.

SOIL SURVEY OF ENGLAND AND WALES

D. A. Osmond

Surveys have been started on Sheets 71 (Selby), 220 (Leighton Buzzard), 239 (Hertford) and 269 (Bridgend) and are being continued on several other sheets previously recorded. The field work has been completed on Sheets 70 (Leeds), 279 (Weston-super-Mare) and 280 (Wells), and any necessary revision is being undertaken. An area of more than 300 sq. miles has been surveyed during the year.

The resignations of two members of the staff have been accepted: J. H. James accepted an appointment with the British Plaster Board Company and D. F. Ball has transferred to the Nature Conservancy. One vacancy has been filled by J. M. Hodgson. Of the members of the Colonial Pool of Soil Surveyors, A. O. Ballantyne and G. F. M. Murdoch are still in N. Rhodesia and Swaziland respectively, while J. C. Chisnall is stationed in Sierra Leone and J. Stark in British Guiana. A. J. Thomasson and R. S. Seale returned from survey work in Iraq, and Seale, together with B. Clayden and C. C. Rudeforth, has returned for a further field season. A. Muir and D. A. Osmond attended the first meeting, at Bonn, of the Working Party on Soil Classification and Survey of the Sub-Commission on Land and Water Use of the European Commission on Agriculture of F.A.O. It was agreed to prepare a soil map of Europe at a scale of about 1 : 1,000,000, and a start has been made by collecting data for Great Britain. Previous to the meeting, all the surveyors were asked to collect information to enable a soil map of England and Wales to be drawn at 1 : 1,250,000. Its production entailed making many widespread traverses and interrupted the normal course of the survey. It was exhibited at the meeting and drew many favourable comments.

D. A. Osmond paid a short visit to Malta to inspect the survey made by D. M. Lang. B. W. Avery was invited to attend a meeting of the German Soil Science Society in Berlin and participated in the excursions afterwards.

Fourteen maps are now in preparation for publication. The Anglesey and Pwllheli sheets of the large New Popular Edition are complete, and will be published during 1958. In view of the increasing amount of work, the staff has been augmented and the processes of production have been amended to cope with the increased demands.

Northumberland

Sheet 19 (Hexham)

Owing to other commitments, the area surveyed is somewhat less than usual, but approximately 28 sq. miles have been mapped, including some representative areas that were selected for detailed

surveys at the scale of 6 inches to 1 mile in order to obtain information as to the series present and their variability. The remainder was surveyed on a reconnaissance basis at the scale of $2\frac{1}{2}$ inches to 1 mile.

The districts covered lie to the south of Hexham, and include the parishes of Shaley and East Hexhamshire. The country rocks belong to the Carboniferous system, but as they rarely outcrop, sedentary soils on them are sparsely distributed and are poorly developed. Most of this area is covered by a shallow drift of local origin. The majority of the soils mapped are of the gley soils group and carry a peaty surface soil, which becomes more strongly developed above altitudes of about 900 feet. On the better-drained sites and on coarse-textured parent materials shallow humus and iron–humus podzols are found. (G. D. Ashley and C. C. Rudeforth.)

Yorkshire

Sheet 71 (*Selby*)

The 6-inch mapping has been extended on Sheet 71 (Selby), where a strip of country flanking the Ouse between York and Selby has been surveyed. About 45 sq. miles have been surveyed.

Apart from recent river alluvium, the materials are entirely of glacial and fluvio-glacial origin associated with the York and Escrick moraines. The soils, which have been described previously, are mostly gley soils and brown earths with gleyed B and C horizons, but on the lighter sands, some of which are wind-blown, gley–podzolic soils occur.

In connection with the proposed 1 : 1,000,000 map of England and Wales a rapid survey of the whole county was made which yielded interesting results. It revealed, for example, that on the rocks of the Carboniferous Limestone Series soils derived solely from the limestone are of relatively small extent compared with those on the Yoredale rocks, which are mainly shales and therefore give soils of very different character. (A. Crompton and C. B. Crampton.)

Lancashire

Sheet 83 (*Formby*)

With the completion of Sheet 74 (Southport) last year, work was started on Sheet 83 (Formby). Since this adjoins previously mapped areas, no new series were required, and approximately 30 sq. miles have been completed. The preparation of maps and a report on the Mosses of South-west Lancashire and requests for information from official bodies which could only be gained by detailed investigation on the ground has occupied a considerable time and reduced the amount of routine mapping. (B. R. Hall.)

Derbyshire

Sheet 125 (*Derby*)

A further 42 sq. miles have been mapped, which almost completes the survey of soils on Triassic rocks occupying the southern margin of the sheet. The survey of the soils developed over Carboniferous

rocks has been extended to the east bank of the Derwent in the vicinity of Belper. In the Derwent valley alluvial soils have been mapped to the north of Derby.

Two new soil series—Kirk Langley and Risley—have been recorded on Triassic parent materials, and other soils have been correlated with the Dunnington Heath series. The Kirk Langley series, previously described as a silty textured soil of the Worcester series, is characterized by a deep profile of medium texture developed over beds of the Keuper that are transitional in lithology between marl and sandstone; the soil drainage is free to slightly imperfect. The Risley series is a freely drained soil developed on glacial drift of mainly Triassic origin. The profile shows a brown or reddish brown sandy loam to loamy sand overlying a sandy loam or loam containing drift pebbles, mainly of quartz and sandstone. The Dunnington Heath series exhibits a composite parent material profile comprising a layer of glacial drift containing pebbles and generally of sandy loam texture overlying Keuper Marl at a depth seldom exceeding 20 inches; drainage is generally slightly imperfect. (J. P. Watson, J. H. James and E. M. Bridges.)

Shropshire

Sheet 166 (Church Stretton)

The survey of soils developed on Old Red Sandstone formations has continued, but it has proved necessary to adopt the Tanyard Complex as a mapping unit over a large part of the region. The Bromyard series (marl phase) and Eardiston series (sandstone phase) occur in such intimate relationships, with no topographical features to aid separation, that it is uneconomical of time to elucidate the soil boundaries.

Gleyed and slightly gleyed soils are found north and north-east of Brown Clee Hill on flat sites which represent the summit levels of the Old Red Sandstone platform. The northern and eastern slopes of the upland region rising from the platform are covered with soliflucted and colluviated material derived from the dolerite and Carboniferous rocks capping the Clee Hill, and several new series have been identified.

The geological complexity of the Titterstone Clee region is reflected in the soil variation, and within a small area podzols, brown earths, gleys, peaty gleys and peaty podzols are found.

More than 60 sq. miles have been mapped, on the Clee Hills and the surrounding platform, and a further 4 sq. miles on the drifts of Apedale, where gleyed and slightly gleyed soils predominate. (D. Mackney and C. P. Burnham.)

Cambridgeshire

Sheets 188 (Cambridge) and 173 (Ely)

A little mapping was done on Sheet 173 in the neighbourhood of Southery, but most of the time was spent in the preparation of the map and memoir for Sheet 188 (Cambridge). During a joint examination of the completed map with D. A. Osmond, it was

decided to modify some of the original series in the light and later knowledge of some of the soils with textural B horizons that possibly resemble the *sols lessivés* of the French workers. Unfortunately the necessary revision interrupted the survey of Sheet 173, but the revised map has now been submitted to the cartographer. (C. A. H. Hodge and R. S. Seale.)

Oxfordshire

Sheet 201 (Banbury)

The soil map of the area surveyed between Banbury and Edge Hill has now been prepared at the 2½-inch scale from the original air photos (scale 1 : 10,000) used in the field. Correlation with the soils mapped on the adjoining Sheet 218 has been good, the actual soil boundaries between the two sheets showing excellent agreement.

Laboratory analysis on soil samples collected during the survey have been completed, and the report is now being written. (R. R. Storrier.)

Sheet 254 (Henley on Thames)

A study of the soils and their relation to landscape form in the Southern Chilterns was begun in October 1956. It has involved a reconnaissance of some 100 sq. miles in South-east Oxfordshire and South-west Buckinghamshire. A detailed survey of 12 sq. miles in a strip from the escarpment at Aston Hill, down the dip-slope to Lane End and thence southward to the Thames at Medmenham included the important landscape features of the larger area. The soils sampled, particularly for mineralogical and micromorphological studies, include representatives of the Winchester and Batcombe series. Preparatory work and detailed mechanical analyses on selected samples have been carried out. (J. Loveday.)

Buckinghamshire and Bedfordshire

Sheet 220 (Leighton Buzzard)

Work was begun in the woodlands between the Brickhills and Millbrook, and later in the season was extended to a few of the larger farms. Three soil complexes have been recognized.

The first is dominated largely by sandy brown earths formed on loose sand from the Lower Greensand; the soils are very acid, freely to excessively drained sands to loamy sands occurring principally in the Bow Brickhill–Aspley Heath area, though they also occur about the Millbrook–Steppingley boundary. Appreciable areas of weakly developed humus podzols are found on Aspley Heath.

The soils of the second complex are chiefly formed on a coarse loamy sand to sandy loam, a glacial drift, largely of Lower Greensand Material but containing foreign stones. It has given rise to freely drained, weakly structured, naturally acid, brown earths. These soils are found in the Charle Wood area of Woburn and the smaller woods farther east, but are probably more extensively represented in the arable areas, where their acidity has been corrected to some extent.

The third complex is dominated by heavy soils with slow internal

drainage that are formed on the Chalky–Jurassic Boulder Clay. These soils are related to the Hanslope series of North Buckinghamshire and Cambridgeshire, though they appear to be less calcareous. They have been mapped in Buttermilk Wood, Woburn Park and farther east in Eversholt and Steppingley; small areas, each of less than 3 acres, occur sporadically in the other complexes. (D. W. King.)

Hertfordshire

Sheet 239 (*Hertford*)

The survey of this sheet was started this year. The area extends from Watford to Waltham Abbey in the south, and from near Luton to Ware along its northern edge. Rothamsted farm lies along the western boundary of the sheet. The area falls naturally into four main regions. On the Clay-with-flints over Chalk in the north-west the soils are similar to the sequence described on Sheet 238 (Aylesbury) (Report No. 5, H.M.S.O., 1953). To the south-east a broad area of glacial deposits runs diagonally from Watford to Ware at about 250 feet O.D. It is a complex of Boulder Clays and Gravels, mainly decalcified at the western end, but calcareous around Ware. Farther to the south-east are Eocene deposits, mainly London Clay, but the soils are often diversified by thin drifts of Pleistocene age. On the eastern boundary the Lea valley, with a large number of small-holdings given over to glasshouse culture and horticulture, forms a fourth region where the soils are mainly formed on later fluviatile drifts.

In order to elucidate the soil pattern associated with these main divisions, detailed mapping was carried out in three districts, at Hatfield Park, Panshanger Park, near Hertingfordbury, and at Thundridge, near Ware. (A. J. Thomasson.)

Glamorgan

Sheet 262 (*Bridgend*)

Survey was started at several localities in order to define some of the main soil series occurring, and some 10 sq. miles have been mapped, mainly on the Lower Lias formation. Three soils of differing drainage classes have been recognized on clays derived from the shales and limestones. The occurrence of poorly drained soils does not appear to be controlled solely by the relief, since they occur on crests and slopes of smooth ridges as well as on almost level sites. Around St. Athans and Llantwit Major freely drained soils are dominant. Imperfectly drained soils are of sporadic occurrence, but are frequently found around Bonvilston.

No attempt has been made to allocate series names at this stage, but it is evident that while some that have already been used are applicable, others are too widely defined. (D. F. Ball.)

Berkshire

Sheet 268 (*Reading*)

Mapping on the 6-inch scale has been initiated in this region, 25 sq. miles having been covered to the south-west of Reading and

in the lower Loddon valley. Much of this consists of level areas of alluvium of various ages, and a complicated pattern of soils has emerged in which marked differences in composition and water regime are manifest. Flanking the alluvial flats are gently sloping, low hills consisting of London Clay, the soils of which are in places directly developed from the clay and are accordingly fine textured, water-retentive and difficult to manage. Many of the London Clay slopes, however, possess a covering of sandy or gravelly material consisting of residual Plateau Gravel or Bagshot Beds material or colluvium derived therefrom; they are more easily managed, although lateral seepage of water through the upper part of the profile due to impedance by the clay below may present a problem to the farmer in wet seasons.

Much of the higher ground is capped with Plateau Gravel, often with thin remnants of Bagshot Beds between it and the London Clay. As in the areas of later alluvium, an intricate soil pattern has been revealed, representing in this case a network of ancient filled-up stream channels, bearing no relation to the surface configuration, in which are found soils markedly different from those elsewhere on the plateaux, e.g., deep fine-textured podzolized gleys as compared with podzols on the gravels. (R. A. Jarvis.)

Somerset

Sheets 280 (Wells) and 279 (Weston-super-Mare)

With the mapping of some 55 sq. miles, the survey of these sheets is complete, but some revision is necessary, particularly of earlier work on Sheet 280. The north-east corner of Sheet 280 consists of well-dissected country, the highest ground being formed by Lias or Coal Measure sandstones and the lower ground by Coal Measure shales or soft Keuper rocks. Of the latter, red sandstones form a considerable area, and the soil, which is often bright red, contains much fine sand and is very similar to soils that have been described near North Petherton in south Somerset. Brown earths on Coal Measure sandstone and gley soils on the shales were correlated with the Nibley and Coalpit Heath series respectively of south Gloucestershire.

Sheet 279 was completed in two districts. The shallow limestone soils of the western Mendip Hills become increasingly contaminated by blown sand towards the coast, reaching a maximum on Brean Down. Deep sandy soils of the Tickenham series occur on footslopes, but their relationship to the Keuper sandstone soils is not clear, for they are not as red and often overlie limestone gravel, but the character and quantity of the sand fraction is very similar. West of the Parret, coastal dunes and shingle are encroaching on the marine alluvium of Steart Point.

Where valleys in the Lias uplands open out to the levels the poorly drained Lias clays grade into Allerton and Wentlloog series. Shales dominate the Lias of this district, so that soils similar to those of the Evesham series are widespread; shallow soils on limestone are rare, and are normally confined to the crests of ridges formed by the outcrops of steeply dipping limestone bands. Remnants of Quantock-derived gravels overlie Lias at about 200 feet

O.D., and at lower levels, particularly around Shurton and Stalford, imperfectly drained, stony, sandy soils are quite extensive on similar gravels. (D. Findlay and B. Clayden.)

Kent

Sheet 305 (Folkestone)

Some time was taken up in the examination of sections exposed during extensive widening operations along several miles of one of the main sewers of Walland Marsh. They furnished further insight into the genesis of the area, and several parts of exceptional interest were described, sampled and photographed. Twenty-two important soils of Romney Marsh were described and sampled.

Surveying was continued in Denge Marsh, and mapping there and in most other outstanding areas of Romney Marsh is now complete.

During the latter part of the season some of the areas which had previously been left on account of crops have been examined, particularly those where more detail is necessary for the preparation of 2½-inch maps. (R. D. Green.)

Other Work

Various glacial drifts entered the area of Sheet 71 (Selby) from several directions, and a mineralogical investigation has been started to determine the relationship between them and the solid rocks on which they rest. (A. Crompton and C. B. Crampton.)

A revision of a soil map of the Experimental Husbandry Farm of the National Agricultural Advisory Service at High Mowthorpe, Yorkshire, has been made in order to provide more detailed information. (A. Crompton and C. B. Crampton.)

Work has been started on a mineralogical study of the parent materials, particularly of those derived from drifts, on Sheet 19 (Hexham) and thin sections of soils are being made for study. (C. C. Rudeforth.)

Co-operation with the National Agricultural Advisory Service has been continued on the problems arising from the sea-flooding in Lincolnshire in 1953 and also on those connected with the restoration of open-cast coal-mining sites. A holding of the Horticultural Land Settlement Association was mapped. (G. D. Ashley.)

At the request of the Ministry of Agriculture, Fisheries and Food, Mossborough Hall Farm, comprising 507 acres, has been mapped at the scale 25 inches to 1 mile. (B. R. Hall.)

One inch to 1 mile texture maps of No. 2 and No. 3 Sub-areas have been compiled at the request of the Merseyside and North Wales Electricity Board. These have been prepared from Geological Survey Drift maps and information gained during reconnaissance soil mapping at the scale 10 miles to 1 inch, of Lancashire, Cheshire and Flintshire. The maps are to be used in connection with future research into earth electrode testing. (B. R. Hall.)

The report and accompanying maps of the Mosses of South-west Lancashire that cover approximately 35,000 acres have been completed, and systematic sampling has been carried out and maps drawn of a proposed drainage scheme for the area. (B. R. Hall.)

Two sites were examined at the request of the Southport Borough Engineer; depths and types of peat were classified and underlying mineral deposits identified. (B. R. Hall.)

A lecture on the Soils of Lancashire was given at the County Agricultural Institute (Hutton), and samples of the main soil types were supplied to the College. (B. R. Hall.)

In collaboration with the Chief Chemist of the East Midland Province, instruction was given to the fieldmen of the Sugar Beet Corporation in the systematic recording of soil profiles in the field. (J. P. Watson and E. M. Bridges.)

The final report on limestone weathering was submitted in connection with investigations on the restoration of open-cast ironstone-mining sites in Lincolnshire. (J. H. James.)

An attempt to correlate soil series and soil fertility was initiated in respect of Derbyshire. (J. P. Watson.)

A survey was made of the National Institute of Agricultural Botany's farm at Lolworth, Cambridgeshire, together with a smaller area adjacent to its headquarters in Cambridge. (C. A. H. Hodge.)

Instruction was given to two members of the Military Engineering Experimental Establishment, Christchurch, in methods of profile description, soil mapping and classification. (R. A. Jarvis.)

Surveys of a number of sites selected for field experiments were examined for the Chemistry Department, Rothamsted Experimental Station. (C. A. H. Hodge, D. W. King, A. J. Thomasson, J. P. Watson and E. M. Bridges.)

A soil map of the Rothamsted Farm was prepared for demonstration purposes. (B. W. Avery.)

The sites of nutritional experiments initiated by E. M. Crowther and Miss B. Benzian in collaboration with the Research Branch of the Forestry Commission have been examined and reports prepared on the site and soil characteristics. (B. W. Avery and D. C. Findlay.)

Advice has been given to the Research Branch of the Forestry Commission on the conduct of soil surveys for use in drawing up working plans for areas scheduled for early replanting. (B. W. Avery.)

B. W. Avery acted as resident tutor in connection with a course on the study of soils in the field, held at the Juniper Hall Field Centre, Dorking.

EYESPOT OF WHEAT AND BARLEY

By

MARY D. GLYNNE AND G. A. SALT

Introduction

A severe disease of wheat, characterized by eye-shaped lesions, was recognized for many years in France (Föex, 1914, 1919; Föex and Rosella, 1930) and in North America (Heald, 1924; McKinney, 1925), but the causative fungus could not be identified because it failed to produce spores in pure culture. Then Sprague (1931) succeeded in obtaining spores of *Cercosporella herpotrichoides* Fron. in pure cultures of the fungus causing eyespot lesions of wheat in Oregon, and Sprague and Fellows (1934) showed that this was also the fungus isolated by Föex in France. Once its identity was established the fungus was recognized in other countries: in Germany (Schaffnit, 1933) and in Denmark (Nielson, 1934); and in 1934 it became severe in Holland, where the wheat acreage had been doubled after the introduction of a wheat subsidy in 1932 (Oört, 1936). These workers, notably Sprague and Fellows (1934) and Oört (1936), found that the disease was influenced by weather and cultural treatments and was worst where cereals were grown frequently. Eyespot is now known to occur in most European countries, in parts of America, Canada, Africa, Australia and New Zealand.

In Britain eyespot was first recognized in the spring of 1935, when wheat on Broadbalk and other fields at Rothamsted were found to have eyespot lesions bearing spores of *C. herpotrichoides* (Glynne, 1936). In the wet summer of 1937 severely lodged wheat on Broadbalk had eyespot lesions on 90 per cent of the straws, whereas equally heavy standing crops on neighbouring fields were almost free from the disease; eyespot was also found associated with lodging in other districts. It then seemed likely that eyespot might increase lodging and reduce yields in this country. A systematic study of the disease was therefore begun to test this possibility, to assess the extent and importance of eyespot in Britain and to obtain quantitative data on the effects of previous cropping and cultural treatments on the disease and on yields of wheat.

Regional surveys were made in many parts of the British Isles, and at Rothamsted the long-term experiments provided a unique opportunity for studying how the disease varies from year to year under similar treatments, and how manurial and other cultural treatments affect its incidence. Problems revealed by field surveys were studied in laboratory, pot and eventually field experiments (these are briefly summarized under the heading "Eyespot" in *Results of Field Experiments* (*R.F.E.*) issued each year by Rothamsted Experimental Station; the Rothamsted Annual Reports also

include brief summaries of some of our results, but will not be referred to here). We now summarize our present knowledge of eyespot as it occurs at Rothamsted and in other parts of the British Isles.

Distribution

Eyespot, first reported only in the southern half of England (Glynne, 1942), is now known to occur all over Britain (Glynne, 1944; Storey, 1947; Glynne and Moore, 1949). It is most often severe on the heavier, better wheat land, least on light, well-drained soil. The order of difference is well illustrated by parallel experiments; on the heavy soil at Rothamsted 64 per cent of the wheat straws were infected at harvest, whereas on the light, sandy soil at Woburn the same variety of wheat treated in the same way had only 2 per cent infected. This advantage, however, was offset by the higher incidence at Woburn of take-all, *Ophiobolus graminis* (which is most severe on light sandy soils) (*R.F.E.* 1956).

History

Eyespot had probably been common on Broadbalk for more than 80 years before the disease was recognized there in 1935; lodging had been recorded on the more fertile plots since 1852, straggling on the less fertile since 1854,* and, on this field, both are chiefly caused by eyespot. The disease had evidently been prevalent in this country for an even longer time. Dialect words such as straggling, brackley, scrawly and scrailing, dating back some 200 years, are still used by farmers to describe wheat crops in which straws fall in all directions as the wheat ripens, and we now know that this condition is mostly a consequence of the eyespot disease. It was probably already prevalent in mediaeval times, when winter wheat alternated with fallow or was followed by spring wheat and then fallow, so that when Richard II says, "We'll make foul weather with despised tears; Our sighs and they shall lodge the summer corn, And make a dearth in this revolting land", Shakespeare (1597) is more likely to have had in mind the untidy sort of lodging caused by eyespot than that associated with over-manuring.

Spore production

The long delay in identifying the fungus is attributable partly to the sterility of its cultures and partly to its slow growth; when attempts were made to isolate it from straw the eyespot fungus was often obscured by more rapidly growing fungi, such as *Fusaria*, which were sometimes mistaken for the causal organism. Sprague (1931) and Sprague and Fellows (1934) obtained spores by growing the fungus in flasks containing cornmeal agar and keeping them outdoors at temperatures fluctuating between −4° and 16° C. The development at Rothamsted of much simpler and more rapid methods for inducing spore formation within a fortnight on small (3-mm.) discs cut from cultures grown in petri dishes, and on infected straws (Glynne, 1953a), have greatly helped both in diagnosis and in studying the disease.

* *Broadbalk White Book* 1843–1912.

Survival and spread

The fungus survives from one crop to another on pieces of stubble which, lying on the surface of the soil, produce immense numbers of spores in cool, damp weather. On Broadbalk these infected straw bases produce spores abundantly from September to April and in some years later. Spores were produced on infected straws in the laboratory at temperatures below 15° C. They were not detached by blowing dry air at them, but were readily freed and carried in mist droplets. Water falling on infected straws carried the spores in splash droplets up 2 feet or more. They germinate readily in water, and may bud off fresh crops of spores from the mycelium in about a week, but they die if kept dry at room temperature for a few hours. Splashed by rain on to young plants, the spores often infect them at about soil level or in the angle made between the first leaves and shoot or at the edge of the coleoptile enveloping the shoot, where moisture is retained long enough for them to germinate and where they are relatively free from competing micro-organisms. A fresh crop of spores is produced on the infected plants in a few weeks, and these are splashed on to surrounding plants. At Rothamsted spores are seldom found on the growing plants after April. The distance travelled by living spores, depending on that travelled by the splash droplets, must vary widely with rain, wind and temperature. Adjacent plots at Rothamsted retain differences in degree of infection from spring to harvest, suggesting that relatively little spread usually occurs from plot to plot, but in one experiment (*R.F.E.* 1955), in a wet, windy season, the fungus was probably carried some 10 yards from heavily to lightly infected plots, in which the straws developed an unusually high proportion of slight lesions, the result of late infections. The distance eyespot spreads from centres of infection in a healthy crop has been roughly estimated (Oört, 1936), but critical trapping work to determine the distance travelled by spores in the field has not yet been done.

Although very dependent on weather, eyespot incidence also depends on the amount of infective material left by preceding crops. This was measured in an experiment (*R.F.E.* 1957) in which wheat in 1957 followed potatoes preceded by wheat (1955) in one block, and in another block wheat followed wheat preceded by beans. In January and February 1957 the pieces of stubble left on the surface of the soil by the preceding wheat crops were collected from sample areas of land and subjected to sporing tests. The wheat grown in 1955 and 1956 respectively had 60 and 78 per cent straws infected at harvest, and in 1957 the stubble from the first crop provided one and from the second twenty-seven pieces of infected stubble per square yard; from these initial sources, 2 and 47 per cent of the plants growing in the 1957 crop were infected in February and 33 and 79 per cent at harvest. Spread of the disease is favoured by cool, damp weather, which prolongs spore production, gives frequent opportunities for dispersal and infection, especially in luxuriant crops which retain moisture; dry, warm, spring weather not only inhibits spore production, but provides fewer opportunities for dispersal and infection, and infected plants may recover from the disease if the outer leaves die before the fungus has penetrated

deeply. Brown-bordered lesions, shaped like an eye, appear within a few weeks of infection, usually on the leaf sheaths. The fungus grows slowly, penetrating successive sheaths, and may kill many tillers and sometimes whole plants in early spring. The fungus eventually penetrates and weakens the central ear-bearing straws; whiteheads with small underdeveloped grain may then result, resembling those caused by take-all, or the straws may fall over, causing straggling in light, lodging in heavy crops.

Increase of eyespot in successive cereal crops

The spread and development of the disease depends so much on the weather that its rate of increase varies greatly in different years and in different parts of the country. Measures that effectively control the disease in most years at Rothamsted and in other parts of southern England are therefore often ineffective in the north and west of the British Isles, where it is cooler and damper in spring and summer. The behaviour of the disease at Rothamsted and in South-east England will first be described and then contrasted with that farther north and west.

At Rothamsted the first wheat crop after several years under grass is usually free from eyespot or very lightly infected; the second may be lightly or moderately infected, but the disease usually becomes severe in the third, or in the fourth successive crop of winter wheat; this also happens in other parts of South-east England, but the second wheat crops after grass are occasionally moderately or severely infected in wetter years (Glynne and Moore, 1949); since 1938 this has occurred once at Rothamsted (*R.F.E.* 1944), when a second crop had 63 per cent straws infected at harvest, but the unusually high proportion, 38 per cent, with slight lesions suggested late infection. On old arable land the disease increases in successive wheat crops in the same way as it does after grass, but sometimes seems to do so rather more rapidly; at Rothamsted the second winter-wheat crop (after 2 years under non-susceptible crops) on old arable land has once been very severely infected (*R.F.E.* 1955), and in a long-term experiment, in which the same crop sequences are followed on both types of land, eyespot is usually more severe on the old arable land (Fosters) than on land which was relatively recently under grass (Highfield).

Once a high level of infection has been reached, eyespot incidence fluctuates from year to year and is influenced both by weather and cultural treatments. Thus on Broadbalk, plots on which wheat follows wheat, the mean percentage of straws infected at harvest on eight typical plots has varied from 40 to 90 per cent since 1938.

Early sowing increases the chances of severe infection more in some years than in others; thus wheat sown in October had significantly more straws infected than that sown in November in 2 years and about the same in two other years (*R.F.E.* 1943–46).

Spring-sown crops have not been more than lightly infected at Rothamsted and, though they occasionally suffer moderate to severe infection in other parts of southern England, they are much less severely infected than autumn-sown crops. Barley, though about as susceptible as wheat, is mostly sown in spring, and even when grown continuously at Rothamsted is only lightly infected.

The infection seems to do little harm to the barley crop, but the infected stubble may produce enough spores to cause severe loss in succeeding wheat crops.

Oats and rye, grown in pot experiments under optimum conditions for infection, developed eyespot lesions more slowly than wheat or barley, and are much less susceptible in the field. One oat crop was moderately infected at Rothamsted, and occasional instances of severe infection of oats have occurred in other south-eastern counties (Glynne and Moore, 1949). However, this happens rather rarely, and at Rothamsted (*R.F.E.* 1953) oats in the rotation were as effective as non-cereal crops in reducing eyespot incidence, but were rather less effective at Sprowston (Batts and Fiddian, 1955). Autumn-sown rye in the six-course rotation at Rothamsted becomes lightly infected, and so, like spring-sown barley, helps the fungus to survive.

In Scotland and Ireland, where cooler, damper weather in late spring and summer favour the spread of infection late in the growing season, eyespot develops more rapidly, so that treatments that rarely lead to severe infection in the south and east often do so in the north and west. Then the second successive crop of winter wheat is often severely infected, spring-sown wheat and barley are often moderately infected in Scotland, severely infected in Ireland; and infected oat crops occur comparatively often (McKay *et al.* 1956).

Although climatic differences account for most of these differences, it is also possible that specialized types of the fungus occur in different regions. In Denmark, wheat and rye grown in a six-course rotation experiment were more severely infected than at Rothamsted. Isolates of the fungus from Danish and English wheat were similar, but that from Danish rye differed from them in cultural characters and infected rye much more severely than did isolates from any other cereal.

Decrease of eyespot under different crops

Land, which had become severely infested by growing successive wheat crops, was used to compare the influence of different crops on eyespot, take-all and weeds appearing in test crops of winter wheat. Crops other than wheat or barley strikingly decreased the infection of subsequent wheat. A single year's break from wheat or barley reduced eyespot; in some years the subsequent wheat crop was lightly, in other years severely, infected. Two-year breaks reduced the disease to a harmless level, and were about as effective as 3-year breaks. Potatoes, beans, fallow and even the slightly susceptible oats and ryegrass all effectively decreased the incidence of eyespot; there were probably differences between them which could be determined in more detailed experiments. These breaks also reduced take-all and weeds and had startling effects on the quantity and quality of grain, which for Squarehead's Master ranged from $15\frac{1}{2}$ cwt./acre in infested plots following wheat to 36 cwt. in plots where eyespot, take-all and weeds had been controlled by previous cropping. Both diseases increased the amount of tailcorn, so that the dressed grain showed even greater differences ranging from 10 in diseased to 33 cwt./acre in healthy crops (*R.F.E.* 1953).

Crop rotation

Regional surveys and field experiments show that, although eyespot incidence varies greatly in the same crop sequence in different years and in different places, the frequency of severe infection is so closely related to previous cropping that this can be used to predict the likelihood of loss from eyespot. Thus at Rothamsted in wheat grown in the four-course rotation experiment (in which wheat and then barley alternate with other crops) the proportion of straws infected at harvest has varied in different years from 3 to 86 per cent; more than half the straws have been infected in 9 out of 20 years. On Broadbalk, where wheat follows wheat, this level has been exceeded in 16 years and in the six-course rotation experiment in only 5 years. Similar effects of previous wheat or barley crops on the frequency of severe infection were evident in regional surveys.

As 2-year breaks (free from self-sown susceptible carriers) have almost always reduced eyespot to a harmless level, it is likely that in some regions the sequence of crops in the four-course rotation experiment might be better if the two non-susceptible crops were grown in successive instead of alternate years, but experiments are needed to discover the conditions under which this would be an improvement. Winter wheat following a 2-year break would normally be free from serious infection; and spring sowing would usually protect the following barley crop from appreciable loss in the south and east, but would fail to do so in the wetter, colder regions. It is, of course, unwise to reverse the order and grow winter wheat after spring barley; the small proportion of plants which become infected in the spring-sown barley after a 2-year break sometimes suffices to affect seriously winter wheat grown the following year, even in the south. This occurred at Rothamsted when, on old arable land, winter wheat following spring barley after a 2-year break was seriously affected by eyespot in 2 out of 4 years (*R.F.E.* 1954, 1955). Three-year breaks, such as occur under grass or lucerne in the Rothamsted ley–arable experiments have consistently given negligible eyespot and correspondingly high yields of wheat.

Lodging

Twenty years ago excess of nitrogen and wet, windy weather were regarded as the chief causes of lodging; but now we know that eyespot is equally important. Very heavy crops may lodge because the straws are not strong enough to withstand the buffeting of wind and rain; then they bend over and lie mostly in one direction. When eyespot has weakened the straw bases, not only do much lighter crops lodge, but the straws, which bend abruptly in the middle of the lesions, fall in all directions and lie flat on the ground; loss from lodging is then added to the direct loss of grain caused by the fungus. Measurements made in many years on hundreds of plots at Rothamsted have shown the highly significant effects on lodging, both of weight of straw and of the proportion with severe eyespot lesions (Glynne, 1951; Salt, 1955). Some idea of their relative effects is shown by mean values obtained on Broadbalk where an increase

in straw weight from 40 to 60 cwt./acre had about as much effect increasing lodging as an increase from 35 to 85 per cent straws with severe eyespot. Wheat following fallow yielded more straw and a smaller proportion with severe eyespot lesions than wheat following wheat; in some years the heavier straw resulted in more lodging, in other years the lower incidence of eyespot resulted in less lodging than after wheat so that long-term averages of the percentage area lodged after wheat and after fallow were about the same (Glynne, 1954).

Because lodging from eyespot causes more loss than non-parasitic lodging, measures to prevent it are most important where cereals are grown frequently on the same land. These measures depend on reducing the severity of eyespot, reducing weight of straw and increasing straw strength; the last two are important whether eyespot is present or not. The methods likely to affect both eyespot and lodging investigated at Rothamsted include varying fertilizers, rate and date of sowing, the use of short, stiff-strawed varieties and spraying with sulphuric acid.

Fertilizers

Fertilizers influence the incidence of eyespot by their effects on plant growth, and they influence lodging by their effects on the disease and on weight of straw.

Increased tillering produces more layers through which the slow-growing fungus must penetrate before it reaches the central ear-bearing straws, thus reducing the severity of eyespot at harvest; but the greater humidity prevailing within a well-tillered crop favours spread of the fungus and development of the disease; the two effects work in opposite directions.

In pot experiments where all plants are infected as seedlings and kept under humid conditions the effect of tillering predominates and well-nourished plants are less severely infected at harvest than starved ones. Applications of nitrogen (Glynne, Dion and Weil, 1945; Salt, 1953) and of phosphate and potash to soil lacking these nutrients greatly decreased the severity of eyespot. In the field the effect of humidity usually predominates, so that fertilizers tend to increase the severity of eyespot at harvest. Because nitrogen is more often deficient than phosphate or potash, it has received most attention. Annual surveys of wheat on Broadbalk show the mean number of severe eyespot lesions in 16 consecutive years was 50 per cent on plot 7 receiving minerals and nitrogen, and 38 per cent on plot 3 receiving no manure. Application of fertilizers appreciably increased incidence of the disease in 10 years and reduced it in only one year. Nitrogenous fertilizers have increased the proportion of straws infected in most of our field experiments; they also increase weight of straw; both effects increase the tendency to lodge and so reduce response to fertilizers. Restricting the fertilizer, though it reduces lodging, also limits yields, so that other methods of control are preferable.

Soil fertility and disease incidence affect the optimum date for applying nitrogen. Early applications increase the weight of straw and the risk of lodging on the better soils. Thus at Rothamsted, on fertile land heavily infested by eyespot, nitrogen applied to Square-

head's Master in March, April and May had little effect on eyespot; that applied in March increased straw and lodging most, and yielded less grain than that applied in May. Where eyespot was controlled and lodging decreased by spraying with sulphuric acid, grain yields were not significantly affected by the date when nitrogen was applied (Salt, 1955).

By contrast, at Woburn on light, nitrogen-deficient soil, there was much less eyespot and no lodging. Plots of Holdfast which received nitrogen in March had more eyespot and yielded 3 cwt./acre less grain than those which received nitrogen in April. Where nitrogen was withheld until May deficiency symptoms became apparent, and although eyespot incidence was the same as after the April application, yields were 6 cwt./acre less (*R.F.E.* 1955).

Seed rate

Lowering seed rate below normal encourages tillering and promotes drying within the crop, and so helps to reduce the incidence and severity of eyespot at harvest. It also reduces competition between shoots for light and nutrients, and so promotes growth of stronger straws, and this helps healthy (Glynne and Slope, 1957) as well as diseased (Glynne, 1951; Salt, 1955) cereals to resist lodging. In an experiment on eyespot-infested land at Rothamsted (Salt, 1955) reducing seed rate of Squarehead's Master wheat from 3 to 1½ bushels/acre decreased severe eyespot from 74 to 56 per cent straws infected, the area lodged from 72 to 40 per cent and increased grain yield from 20 to 25 cwt./acre. In several experiments plots, sown at the normal seed rate and given nitrogenous fertilizer, suffered so much loss from disease that they yielded less than plots sown at half the seed rate and given no nitrogen; thinly sown plots dressed with nitrogen yielded most grain. Thin sowing has the additional advantage that it reduces the effects of take-all by encouraging plants to produce more roots. Its main disadvantage is that it encourages the growth of weeds, and these must be controlled for thin sowing to be advantageous. Failure to control weeds accounts for inconsistent effects of seed rate on infested land at Rothamsted and Woburn (*R.F.E.* 1955, 1956).

Optimum sowing rates therefore vary, not only with soil, variety, nutrition and weather, but also with disease incidence; they are higher on land free from eyespot and take-all than where either of these diseases is severe.

Varietal susceptibility

Many types of wheat tested in pot experiments all proved susceptible; they included the wild type *Triticum monococcum* and representatives of groups with fourteen, twenty-eight and forty-two chromosomes. Differences in severity of infection of different varieties were evident in field experiments; Deprez 80 had consistently fewer straws infected at harvest than three other varieties (*R.F.E.* 1943–46) and Cappelle (1952) had 31 per cent severely infected straws when Squarehead's Master had 88 per cent. Similar differences were found in a pot experiment (1953) when inoculated Cappelle and Scandia all developed lesions but had only half as many straws severely infected at harvest as four other varieties,

and mean loss in grain from infection was 9 per cent in Cappelle, 12 per cent in Scandia, as compared with 20–28 per cent in other varieties. Lower field susceptibility of Cappelle was found in France (Vincent *et al.*, 1952), in Cambridge (Lupton and Macer, 1955) and was evident in experiments at Rothamsted and Woburn (*R.F.E.* 1953–56). Cappelle has the further advantage of a short, strong straw which seldom lodges. Unfortunately it is just as severely attacked by take-all as other varieties, and the serious loss caused by take-all and eyespot are less easily noticed because it yields more than many other varieties; but the serious loss suffered by Cappelle was dramatically apparent in 1955, when, sown in early October on fertile land supplied with ample nutrients, it yielded only 25 cwt./acre on plots severely infested by eyespot and take-all, and 61 cwt./acre where these diseases (and weeds) had been controlled by previous cropping.

Spraying with sulphuric acid

In South-east England cereals were sometimes sprayed with sulphuric acid in spring to control weeds; in France attempts to use it to control foot and root rots gave variable results. At Rothamsted effects of the acid on spore production were studied in the laboratory and its effects on crops studied in field experiments (Dion, 1943). Application of 12½ per cent by volume commercial sulphuric acid at 100 gallons/acre, after sowing and before emergence, stopped spore production on exposed pieces of stubble and prevented early infection of the crop. But the disease spread in spring, possibly from pieces of freshly exposed stubble. The best results followed two sprayings, one applied to the soil in autumn after sowing, the other applied to the crop in early spring. A single spraying was most effective when applied at the five-leaf stage, before the fungus had penetrated beyond the second leaf sheath, which, with outer leaves, was killed by the spray. At Rothamsted this stage is usually reached in the first half of March. By April the fungus had penetrated too deeply to be controlled by spraying, although, like the earlier treatment, it controlled weeds. The acid had little effect on straw yield, but, by reducing eyespot, greatly reduced lodging; it was most successful on well-nourished crops, giving in some years yield increases of 10 cwt./acre (Glynne, 1951; Salt, 1955); but it has sometimes failed to control eyespot or to increase yields (*R.F.E.* 1956; Salt, 1957).

Acid spraying has proved valuable in experiments in which effects of treatments are compared on lightly and heavily infected crops, but its use in farming is likely to be limited. The land is sometimes so wet in early March that the machinery needed for high-volume spraying damages the crop excessively, and reports of low-volume spraying have not been encouraging. But the impressive effects of successful spraying with sulphuric acid suggest that the use of other chemical sprays might usefully be investigated.

Yield of grain

The loss caused by eyespot varies with cultural and manurial treatments; in pot experiments inoculation reduced yields by 19 per cent in well-nourished, by 86 per cent in starved plants; by 22

per cent in thinly and 45 per cent in thickly sown plants. In a series of pot experiments in which all inoculated plants were infected and some straws straggled there was no general lodging, and loss caused by eyespot averaged 33 per cent. Losses of the same magnitude occur in the field, where, although some plants escape infection, loss from lodging must be added to that caused directly by the fungus. Straws with severe lesions, taken from field experiments, yielded only about half as much grain as uninfected straws or those with slight lesions (Glynne, 1944, 1953b).

Take-all and weeds increase with eyespot in field experiments, so that it is often difficult to assess their separate effects. Where eyespot and weeds, but not take-all, were controlled by spraying with sulphuric acid, yields were increased by 46 per cent in 1948, by 39 per cent in 1951. Where take-all was also controlled by previous cropping yield increases have exceeded 80 per cent (*R.F.E.* 1955–56). In experiments which measured effects of previous cropping on a final test crop of winter wheat, take-all and weeds increased and yields decreased in successive wheat crops. Typical figures for plots which carried the first, second and third crops of winter wheat were respectively 37, 28 and 19 cwt./acre for Squarehead's Master in 1953, and in 1956, 37, 24 and 19 cwt./acre for Holdfast, 49, 36 and 24 cwt./acre for Cappelle, and the heaviest crops included least tail corn, so that dressed grain showed even bigger contrasts.

The development of high-yielding varieties which resist lodging, generous application of fertilizers and improved cultural and harvesting methods have greatly increased yields of wheat in recent years. But they fail to give high yields if eyespot and its associated troubles are not controlled. Recognition of the severity and frequency of losses caused by soil-borne diseases have shown that yields of wheat previously regarded as satisfactory are really too low. This has helped to set a higher standard for wheat yields at Rothamsted. Here, yields of 40–45 cwt./acre were regarded as exceptionally high less than a decade ago, but, by deliberately combining favourable treatments on uninfested land, yields of 50–60 cwt./acre have been obtained in each of the last 3 years. Further knowledge and wider application of that already acquired can do much to increase yields of wheat in Britain.

References

Batts, C. C. V. & Fiddian, W. E. H. (1955). *Plant Path.* **4**, 25.
Dion, W. M. (1943). Ph.D. thesis (London University).
Föex, E. (1914). *Bull. Soc. Path. vég. Fr.* **1**, 26.
Föex, E. (1919). *Ibid.* **6**, 52.
Föex, E. & Rosella, E. (1930). *Ann. Epiphyt.* **16**, 51.
Glynne, Mary D. (1936). *Trans. Brit. mycol. Soc.* **20**, 120.
Glynne, Mary D. (1942). *Ann. appl. Biol.* **29**, 254.
Glynne, Mary D. (1944). *Ibid.* **31**, 377.
Glynne, Mary D. (1946). *Ibid.* **33**, 35.
Glynne, Mary D. (1951). *Ibid.* **38**, 665.
Glynne, Mary D. (1953a). *Trans. Brit. mycol. Soc.* **36**, 46.
Glynne, Mary D. (1953b). *Ann. appl. Biol.* **40**, 221.
Glynne, Mary D. (1954). *Congr. int. Bot.* **8**, 18–20, p. 134.
Glynne, Mary D., Dion, W. M. & Weil, J. W. (1945). *Ann. appl. Biol.* **32**, 297.

Glynne, Mary D. & Moore, F. Joan (1949). *Ibid.* **36**, 341.
Glynne, Mary D. & Slope, D. B. (1957). *J. agric. Sci.* **49**, 454.
Heald, F. D. (1924). *Bull. Wash. agric. Exp. Sta.* **155**(1920), 38; **167** (1922), 39; **175**(1922), 36; **187**(1924), 71.
Lupton, F. G. H. & Macer, R. C. F. (1955). *Agriculture, Lond.* **62**, 54.
McKay, R., Loughnane, J. B. & Kavanagh, T. (1956). *Nature, Lond.* **177**, 193.
McKinney, H. H. (1925). *U.S. Dep. Agric. Bull.* 1347, 40.
Nielson, O. (1934). *Statens plantepatol. Forsøg*, 5.
Oört, A. J. P. (1936). *Tijdschr. PlZiekt.* **42**e, 179.
Salt, G. A. (1953). Ph.D. thesis (London University).
Salt, G. A. (1955). *J. agric. Sci.* **46**, 407.
Salt, G. A. (1957). *Ibid.* **48**, 326.
Schaffnit, E. (1933). *Phytopath. Z.* **5**, 493.
Shakespeare, William (1597). *Richard II*, Act 3, Scene 3.
Sprague, R. (1931). *Science* (N.S.) **74**, 51.
Sprague, R. & Fellows, H. (1934). *Tech. Bull. U.S. Dept. Agric.* 428.
Storey, I. F. (1947). *Ann. appl. Biol.* **34**, 546.
Vincent, A., Ponchet, J. & Koller, J. (1952). *Ann. Inst. Rech. agron. Paris*, Sér. 3, **3**, 459.

BRACKEN THIAMINASE

By

R. H. Kenten

Studies of enzymes *in vitro* led to the discovery, some thirty or forty years ago, that on occasion, compounds of similar structure to the substrate were capable of competitively inhibiting the enzyme activity. Later, it was demonstrated that the bacteriostatic action of sulphanilamide was antagonized by the essential metabolite *p*-aminobenzoic acid. This led to the Woods–Fildes hypothesis, which contends that because of the structural similarity of sulphanilamide and *p*-aminobenzoic acid, sulphanilamide blocks the enzyme system concerned with the metabolism of *p*-aminobenzoic acid and interferes so much with an essential metabolic function of the bacterium that growth is inhibited. Sulphanilamide and *p*-aminobenzoic acid compete for the enzyme system, and bacteriostasis results when the inhibitor is successful in the competition. It was then recognized that chemotherapeutic substances might be designed by the synthesis of substances of analogous structures to essential metabolites, thereby destroying the organism by a competitive antagonism of the essential metabolite. However, because of the present limited state of our knowledge of the multitude of co-ordinated reactions which are an essential and indispensable condition of the existence of organisms, attempts to design chemotherapeutic substances in this way have met with little success. It is certain, however, that as biochemical knowledge accumulates, living processes will become more and more susceptible to control and that an increasing number of drugs, weedkillers and insecticides will be deliberately designed and synthesized. It is for the purpose of obtaining such knowledge that a study of the enzymes of bracken (*Pteridium aquilinum* (L.) Kühn) has been undertaken; for none of the weedkillers which have been tested have proved to be practically useful for eradicating bracken specifically. The investigations so far have only occupied part of the time over the past three years and although a number of the enzymes common among other organisms have been identified in bracken, as yet our knowledge is fragmentary and unco-ordinated and only the work done on bracken thiaminase will be discussed here.

Introduction

Thiaminases were first recognized in certain species of fishes. Their discovery followed the demonstration that the disease in animal populations known as " Chastek paralysis " was in fact a thiamine (vitamin B1) deficiency and developed when certain species of raw fish were included in the diet of foxes, although thiamine was present in adequate amounts. The substance in fish responsible for the destruction of the dietary thiamine was shown to be an en-

zyme by Sealock, Livermore and Evans (1943). The relevant literature has been reviewed by Yudkin (1949) and Harris (1951).

The thiaminases are enzymes which catalyse the fission of the methylene–quaternary-nitrogen bond of thiamine (Fig. 1). This usually occurs only in the presence of certain amines, the pyrimidine moiety being transferred to the amine according to the general equation,

$$P\text{–}CH_2\text{–}T^+ + RNH_2 \longrightarrow P\text{–}CH_2\text{–}NHR + T + H^+ \quad . \quad (1)$$

where P and T stand for the pyrimidine and thiazole components of thiamine respectively (Woolley, 1953; Fujita *et al.*, 1952; Sealock and Davis, 1949). Thiaminases catalysing the transfer reaction have been found in fishes, shellfish, bacteria and ferns (Harris, 1951; Fujita, 1954), but only with the bacterium *Bacillus aneurinolyticus* Kimura et Aoyama is there good evidence of the production of a thiaminase capable of catalysing the hydrolytic fission of thiamine (Fujita, Nose and Kuratani, 1954)

$$P\text{–}CH_2\text{–}T^+ + H_2O \longrightarrow P\text{–}CH_2OH + T + H^+ \quad . \quad . \quad (2)$$

Studies of plant thiaminase stem from the observation of Weswig, Freed and Haag (1946) that rats fed on a ration containing 40 per cent of air-dried bracken and adequate thiamine developed acute thiamine deficiency. Thomas and Walker (1949) confirmed this work and showed that bracken contained a thermolabile system capable of destroying thiamine. The active system was extracted from the dried leaf by Evans, Jones and Evans (1950), who concluded that it contained an enzyme and established that the thiazole component of thiamine was one of the products of the reaction. The situation was, however, complicated by the reports of Somogyi (1949) and Somogyi and Muralt (1949) that the factor responsible for the inactivation of thiamine in fern and bracken extracts was thermostable and passed a dialysing membrane. Subsequently, Evans and Jones (1952) obtained evidence that aqueous extracts of bracken contained an enzyme capable of catalysing the transfer reaction of equation (1), but the work of Fujita, Okamoto and Nose (1955) with the variety of bracken *var. japonicum* suggested that an enzyme was present which was capable of catalysing both the transfer and the hydrolytic fission reactions (equations 1 and 2).

It was known that horses suffer from thiamine deficiency when the proportion of bracken in their diet is high (Roberts, Evans and Evans, 1949) and it seemed likely that the deficiency was brought about by the destruction of the dietary thiamine by factors in the bracken. It follows therefore that such factors are unlikely to be present in the common plants of pastures. Also, Fujita (1954) examined large numbers of higher plants for the presence of thiaminase and found activity only in the herb *Celosia crista.*

Apart from the need to clarify the conflicting reports of the nature of the thiamine-destroying factors which are present in bracken, it was of particular importance to establish whether an enzyme system which attacked thiamine was present in bracken but absent from most of the higher plants. Such a difference might be exploited for the development of a specific bracken-killing agent.

Preliminary experiments

Examination of aqueous extracts of dried and fresh bracken showed that the destruction of added thiamine was small and that it could be greatly increased by the addition of certain amines. Further, over 90 per cent of the activity was abolished by heating the extracts for 15 minutes at 100°. These results, in agreement with those of Evans and co-workers, suggested that the bracken extracts contained a thiaminase capable of catalysing the transfer reaction according to equation (1). Previously, thiaminase activity had been followed by measuring the disappearance of thiamine, although evidence for the transfer reaction had been got by the isolation of the pyrimidine–amine product, or by fluorimetric or chromatographic techniques. As a result of the preliminary experiments, it became clear that it would be desirable to develop a method by which the formation of the pyrimidine–amine product could be measured. The availability of such a method would make it possible to determine the precise nature of the reaction by which thiamine was destroyed. For the activating effect of amines might have been due either to their stimulating the hydrolytic fission of thiamine or to their entering into the transfer reaction.

Spectrophotometric method of estimating thiaminase transfer activity

Tests with a variety of amines suggested that bracken thiaminase destroyed thiamine most readily in the presence of pyridine. If the transfer reaction was involved it would lead to the production of 1 mol. *N* - (4 - amino - 2 - methylpyrimidin - 5 - yl) - methylpyridine heteropyrithiamine, called HPT hereafter, Fig. 1) per mol. of thiamine destroyed and could be followed by measuring the rate of formation of HPT. A method of estimating small amounts of HPT in the presence of thiamine was therefore worked out (Kenten 1957). The method depends on the destruction of thiamine by incubation with strong alkali and subsequent oxidation of the HPT to 2-methyl-pyrichromine by alkaline ferricyanide. The 2-methyl-pyrichromine is estimated spectrophotometrically at 386 mμ. Using this method, studies were made of the effect of pH, thiamine concentration and pyridine concentration on the rate of formation of HPT by extracts and partially purified thiaminase preparations from bracken.

These studies helped to establish standard conditions for the estimation of thiaminase activity under which the rate of formation of HPT was directly proportional to the amount of extract or thiaminase preparation present. This new method was of value in following the thiaminase activity in work on the purification of bracken thiaminase. Kenten (1957) defined one unit of thiaminase activity as that amount of enzyme which catalyses the formation of 1 μmole of HPT in 1 hour under the standard conditions, and the specific activity as the number of enzyme units/mg. of N of the enzyme preparation.

The course of the reaction

Using either water extracts of dried bracken leaf or partially purified thiaminase preparations, it was shown that in the presence

of pyridine 90–95 per cent of the thiamine added was converted to HPT. The activity was virtually completely destroyed by heating the extracts or thiaminase preparations for 15 minutes at 100° before testing. With the small amounts of extract used no destruction of thiamine in the absence of pyridine could be detected. These results suggested that destruction of thiamine with both the extracts and the partially purified thiaminase preparations took place through the transfer reaction and that side reactions were small.

By fractionation with ammonium sulphate and calcium phosphate gel, concentrated, partially purified thiaminase preparations were made from water extracts of dried bracken leaves. The best preparation represented a purification of about sixty-fold. It catalysed the formation of 3,150 μmole of HPT/hour/mg. of N of the preparation under the standard conditions. Using such preparations, no evidence was obtained that they were capable of catalysing the destruction of thiamine in the absence of amines.

Difference between bracken and higher plants and its bearing on bracken eradication

It was therefore clearly established that bracken contained a thiaminase capable of catalysing the transfer reaction (equation 1), but without significant hydrolytic activity (equation 2). Tests with a number of higher plants failed to provide any evidence for the presence of an enzyme system capable of destroying thiamine. This difference suggested two possible lines of approach towards the development of a specific bracken-killing agent. In the first place, it might be possible to synthesize a thiamine analogue which would not be attacked by thiaminase but which would combine with it and destroy its catalytic activity. If the thiaminase system is essential, then introduction of such a compound into the bracken plant might inactivate this system and so disturb the metabolism of the plant that its death would follow. Secondly, it might be possible to introduce a substance into the bracken plant on which the thiaminase would act to release a toxic compound. That this latter type of approach can be successful has been demonstrated by Wain and co-workers (Wain, 1956). With certain homologues of the substituted phenoxyacetic acids, selectivity was achieved by exploiting differences in the β-oxidation systems of plants; only certain plants having the capacity to convert the homologues into the phytotoxic substituted phenoxyacetic acids.

To facilitate studies of the action of bracken thiaminase on thiamine analogues it was necessary to develop a general method for following thiaminase action. The spectrophotometric method described previously can be used only when pyridine is the acceptor amine and heteropyrithiamine is one of the products of the reaction.

Manometric studies of bracken thiaminase

Since both the reactants and the products of the thiaminase transfer reaction are bases and the extent of ionization of the products, at about neutral pH, may differ from that of the reactants, acid may be released. If the reaction takes place in bicarbonate–CO_2 buffer, the amount of acid released, and hence the extent of

thiaminase action, can be followed manometrically by measuring the evolution of CO_2.

The following examples of systems in bicarbonate–CO_2 at pH 7·5 make this clear. If the acceptor amine is a strong, or moderately strong base (pKa 10 or greater), then the two extreme possibilities may be written

$$P\text{–}CH_2\text{–}T^+ + RNH_3^+ \longrightarrow P\text{–}CH_2\text{–}NH_2^+R + T + H^+ \quad (3)$$

$$P\text{–}CH_2\text{–}T^+ + RNH_3^+ \longrightarrow P\text{–}CH_2\text{–}NHR + T + 2H^+ \quad (4)$$

and between 1 and 2 mol. of acid would be released according to the extent of ionization of the pyrimidylmethyl–amine product. If the acceptor amine is a very weak base (pKa 5 or less) and the pyrimidylmethyl–amine product is a strong base, then the reaction can be formulated

$$P\text{–}CH_2\text{–}T^+ + RNH_2 \longrightarrow P\text{–}CH_2\text{–}NH_2^+R + T \quad . \quad (5)$$

and no release of acid, and hence no evolution of CO_2, would take place. For studying such systems (equation 5) therefore, the manometric method is not suitable, but they can be avoided by the choice of an amine acceptor of suitable pKa.

Quantitative studies using aniline, pyridine, piperidine and trimethylamine showed that, although a small part (5–10 per cent) of the thiamine was lost by side reactions under certain conditions, there was a reasonable agreement (within 10 per cent) between the calculated and experimental outputs of CO_2 (Kenten, 1958). This suggested that the method was suitable for studying the action of thiaminase, and it was accordingly used to test the activity of thiaminase towards structural analogues of thiamine.

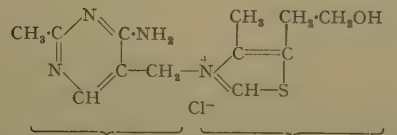
Behaviour of thiaminase with structural analogues of thiamine

Thiamine analogues were synthesized which differed in structure from that of thiamine in that only the thiazole portion was replaced by different amines.

The results of manometric tests with these compounds showed that some of them were attacked by the bracken thiaminase and that none of them, when present in relatively small amounts ($5 \times 10^{-3}M$), was capable of appreciably inhibiting the action of bracken thiaminase on thiamine. In particular, heteropyrithiamine and quinilinothiamine (Fig. 1), in which pyridine and quinoline replace the thiazole heterocycle, were readily attacked by thiaminase at about half the rate of that with thiamine. When the primary amino group of thiamine, which is carried on the pyrimidine portion of the molecule, was replaced by hydroxyl the resultant compound, oxythiamine, was attacked very slowly. Oxythiamine at concentrations of $5 \times 10^{-3}M$ was, however, without appreciable effect on the rate of the thiaminase reaction with thiamine. These results suggested that in searching for a structural inhibitor of thiaminase a more profitable approach would be to vary the nature of the pyrimidine component of thiamine. Accordingly, several analogues were synthesized in which the pyrimidine heterocycle was replaced by a substituted benzene ring and in which the thiazole component was the same, or very nearly the same, as that of thiamine. Tests

showed that none of these compounds was attacked by thiaminase. One of them, 3-(*o*-aminobenzyl)-4-methylthiazole (ABMT, Fig. 1), was found to be a very powerful inhibitor of thiaminase action. Concentrations of 2X $10^{-6}M$ ABMT inhibited bracken thiaminase by 15–20 per cent and at $5 \times 10^{-5}M$ inhibition was virtually complete (Kenten, 1958). The structural requirements for inhibition appear to be very exacting, for if the amino-group of ABMT is replaced by a nitro-group the capacity to inhibit thiaminase is lost; $5 \times 10^{-3}M$ concentrations of the nitro-compound being without

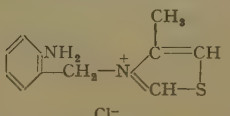
FIG. 1.



Pyrimidine moiety (P) Thiazole moiety (T)

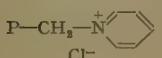
Thiamine

N-(4-amino-2-methylpyrimidin-5-yl)methyl-5-(β-hydroxyethyl)-4-methyl thiazolium chloride



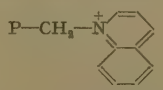
ABMT

3-(*o*-aminobenzyl)-4-methylthiazolium chloride



Heteropyrithiamine

N-(4-amino-2-methylpyrimidin-5-yl) methylpyridinium chloride



Quinilinothiamine

N-(4-amino-2-methylpyrimidin-5-yl) methylquinolium chloride

effect. Inhibition of thiaminase by ABMT would be expected to be competitive because of its structural resemblance to thiamine, and in fact Sealock and Goodland (1944) have obtained evidence that fish thiaminase is inhibited competitively by ABMT. With bracken thiaminase, however, the inhibition is not competitive because increasing the concentration of thiamine fails to decrease the amount of inhibition. Also, the amount of inhibition increases with increase in time of exposure of the thiaminase to the ABMT. It is possible that the ABMT initially combines reversibly with the enzyme at the same site as thiamine but that a second irreversible reaction follows which gives an inactive ABMT–enzyme complex.

Injection of ABMT into bracken

Single injections of up to 5 mg. of ABMT into the stems of bracken fronds caused no obvious damage to develop in a period

of 3–4 weeks. These injections were made into pot-grown bracken in early August, when growth was almost complete. The size of the fronds was such that, assuming even distribution, the concentration of ABMT in the frond would be at least $3 \times 10^{-4}M$; *in vitro* $5 \times 10^{-5}M$ ABMT is sufficient to bring about nearly complete inhibition of the thiaminase system.

There are several reasons why the ABMT should have failed to affect the bracken. In the first place, it may not have been translocated to the site of thiaminase action. Secondly, it may have been attacked by another enzyme system in the bracken and its capacity to inhibit thiaminase destroyed. Thirdly, it may be that the thiaminase system is not important, or only important at certain stages of growth, to the metabolism of bracken.

Thiaminase substrates which could give rise to a phytotoxic substance

It has been shown that thiaminase can act on certain thiamine analogues in which the thiazole component has been replaced by another amine. If this amine were a phytotoxic substance (X), then it is possible that combination with the pyrimidylmethyl component of thiamine might mask its toxic properties. Thus, if the pyrimidylmethyl-X compound were administered to a mixed population of plants it might be expected that only those containing the thiaminase system (i.e., bracken and other Pteridophytes) would be capable of splitting it and releasing the toxic substance X.

$$\text{P–CH}_2\text{–X} + \text{RNH}_2 \longrightarrow \text{P–CH}_2\text{–NHR} + \text{X}$$

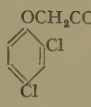
Few amines are known which are toxic to plants when administered in very small quantities. The amino-compounds, 1-*iso*propyl-2-nonyl-4 : 4-dimethyl-2-imidazoline (Allen and Skoog, 1951) and (5-chloro-2-benzimidazolylthio)-acetic acid (Rebstock, Ball, Hamner and Sell, 1957) are known to cause severe damage or kill certain plants, but when these were injected into bracken fronds in amounts of up to 5 mg. the only obvious effect was a slight chlorosis at the tip of the frond with the higher amounts of the latter compound.

Because of the readiness with which heteropyrithiamine and quinilinothiamine were attacked by bracken thiaminase, it seemed likely that a thiamine analogue containing a substituted pyridine ring in place of the thiazole would also be attacked. It was decided therefore to synthesize some pyridine analogues of the phytotoxic phenoxyacetic acids. Since quite small modification of a molecule can abolish phytotoxicity, the chances that the pyridine compounds would have toxic properties were small. However, the structural requirements for phytotoxicity are not clearly understood, and there were no other grounds on which to base the choice of structures. Two compounds were synthesized (Fig. 2), 6-chloro-2-methylpyridin-3-oxyacetic acid and 5-bromopyridin-3-oxyacetic acid. These compounds had no obvious effect on bracken when injected into the fronds as described above; they were also without significant activity as compared with 2 : 4-D or MCPA in inhibiting the germination of cress seeds.

Because of the lack of toxicity of these imidazole and pyridine derivatives, no attempt was made to synthesize and test the pyri-

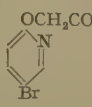
midylmethyl-substituted compounds. It may be that other amines, for example, pyridine compounds with halogen or halogen and methyl substituents in other positions, will prove to be toxic to bracken, and there is scope here for much further work.

FIG. 2.

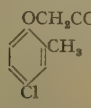


2 : 4D

2 : 4-dichlorophenoxyacetic acid

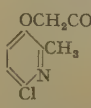


5-bromopyridin-2-oxyacetic acid



MCPA

4-chloro-2-methylphenoxyacetic acid



6-chloro-2-methylpyridin-3-oxyacetic acid

The role of thiaminase

The physiological role of thiaminase is not clear. Thiamine apparently has a limited and erratic distribution (Harris, 1951; Fujita, 1954). Among the fishes, for example, it occurs only in some fresh-water and salt-water species. It could be that thiaminase has some special role in those organisms in which it occurs. Alternatively, *in vivo* it may catalyse a reaction common to most organisms and only show activity with thiamine *in vitro* in certain cases. If thiamine is the substrate of thiaminase *in vivo*, then thiaminase would catalyse the synthesis of thiamine analogues having an amine other than the thiazole moiety of thiamine attached to the methylene bridge. Such compounds are as yet unknown in biological material. From the activity of thiaminase in bracken extracts it can be calculated that the rate of metabolism of thiamine by thiaminase in the fresh leaf could be of the order of 4,000 μg./g. of leaf/hour at 17° C. Watanabe (1952) finds that bracken contains 0·66 μg. of thiamine/g. fresh weight.

With certain amines the transfer reaction is reversible. Therefore the possibility exists that thiaminase takes part in the synthesis of thiamine by catalysing the exchange of 5-β-hydroxyethyl-4-methyl thiazole with a pyrimidinmethylamine precursor. Such a role for thiaminase would appear to presuppose different pathways of thiamine synthesis in, for example, different but closely related fishes.

The present work and that of Fujita (1954) show that thiaminase will act on certain thiamine analogues. Also Woolley (1953) has found that carp thiaminase catalyses the transfer reaction between the pteridine analogue of thiamine and *p*-aminobenzoic acid or *p*-aminobenzoylglutamic acid, with the formation of pteroic acid or pteroylglutamic acid, although the yields were extremely small.

Woolley does not consider that this is the mode of biosynthesis of these compounds. The results do, however, indicate the potentialities of thiaminase as a synthesizing enzyme.

The results of the present work with bracken thiaminase and that with other thiaminases suggests that for the transfer reaction to take place readily the substrate must have a pyrimidine ring attached by a methylene bridge to an amine. The nature of the amine may be varied widely, but little variation in the pyrimidine ring is permissible. It is therefore of particular interest that preliminary results suggest that certain purines and pyrimidines are active as acceptor amines in the bracken thiaminase transfer reaction. It may be that the physiological function of thiaminase lies in the metabolism of these compounds or in helping in such actions as the nucleic acids may be concerned in, and that is not restricted to reactions involving thiamine.

Conclusion

Although the investigations have as yet produced no results of immediate practical value for the eradication of bracken, a start has been made on the synthesis of compounds which may be of value, and a good deal of information about the thiaminase system has been obtained. New techniques for studying thiaminase action have been developed, and the information obtained by these methods will help to elucidate the physiological role of thiaminase. In particular, the investigations have shown that ABMT is a powerful inhibitor of thiaminase *in vitro*, although it is apparently without effect on the bracken plant. Further studies of compounds having a close structural resemblance to ABMT would appear to be worthwhile, as the availability of compounds which would inhibit thiaminase *in vivo* might help to throw light on the role of this enzyme and might also be useful as bracken-killing agents.

References

Allen, S. E. & Skoog, F. (1951). Phytotoxicity of imidazoline derivatives and related compounds. *Plant Physiol.* **26**, 611.

Evans, W. C. & Jones, N. R. (1952). Plant thiaminases. *Biochem. J.* **50**, xxviii.

Evans, W. C., Jones, N. R. & Evans, R. A. (1950). The mechanism of the anti-aneurin activity of bracken. *Biochem. J.* **46**, xxxviii.

Fujita, A., Nose, Y. & Kuratani, K. (1954). The second type of bacterial thiaminase. *J. Vitaminol. Japan*, **1**, no. 1, 1.

Fujita, A. (1954). Thiaminase. *Advanc. Enzymol.* **15**, 389.

Fujita, A., Nose, Y., Kozuka, S., Tashiro, T., Ueda, K. & Sakamoto, S. (1952). Studies on thiaminase. *J. biol. Chem.* **196**, 289.

Fujita, A., Okamoto, T. & Nose, Y. (1955). Antithiamine factors of ferns. *J. Vitaminol. Japan*, **1**, no. 2, 24.

Harris, R. S. (1951). Thiaminase. *In*: The Enzymes, Vol. 1, Part 2, p. 1186. New York: Academic Press.

Kenten, R. H. (1957). The partial purification and properties of a thiaminase from bracken. *Biochem. J.* **67**, 25.

Kenten, R. H. (1958). Manometric studies of bracken thiaminase. *Biochem. J.* (in the press).

Rebstock, T. L., Ball, C. D., Hamner, C. L. & Sell, H. M. (1957). Effect of chemical structure on the growth inhibition of plants with some acid analogues of 2-mercaptobenzimidazole. *Plant Physiol.* **32**, 19.

Roberts, H. E., Evans, E. T. R. & Evans, W. C. (1949). Production of "Bracken staggers" in the horse and its treatment by Vitamin B1 therapy. *Vet. Rec.* **61**, 549.

SEALOCK, R. R. & DAVIS, N. C. (1949). The activating effect of *m*-nitroaniline on thiamine destruction by the Chastek-paralysis enzyme. *J. biol. Chem.* **177**, 987.

SEALOCK, R. R., LIVERMORE, A. H. & EVANS, C. A. (1943). Thiamine inactivation by the fresh-fish or Chastek-paralysis factor. *J. Amer. chem. Soc.* **65**, 935.

SEALOCK, R. R. & GOODLAND, R. L. (1944). Thiamine inactivation by the Chastek-paralysis factor. *J. Amer. chem. Soc.* **66**, 507.

THOMAS, B. & WALKER, H. F. (1949). The inactivation of thiamin by bracken. *J. Soc. chem. Ind., Lond.* **68**, 6.

SOMOGYI, J. C. (1949). Inactivation of aneurin by extracts of animal and plant tissues. *Int. Z. Vitaminforsch.* **21**, 341.

SOMOGYI, J. C. & MURALT, A. (1949). Inactivation of thiamine by ferm extracts. *Helv. physiol. Acta*, **7**, C56.

WAIN, R. L. (1956). The regulation of plant growth with chemicals. *Sci. Progr.* **64**, 604.

WATANABE, H. (1952). *Japan. J. Nation's Health*, **21**, 134. (Cited in *Chem. Abstr.* (1953), **47**, 11384c).

WESWIG, P. H., FREED, A. M. & HAAG, J. R. (1946). Antithiamine activity of plant materials. *J. biol. Chem.* **165**, 737.

WOOLLEY, D. W. (1953). Biosynthesis and energy transport by enzymic reduction of " onium " salts. *Nature, Lond.* **171**, 323.

YUDKIN, W. H. (1949). Thiaminase. *Physiol. Rev.* **29**, 389.

THE RESIDUAL EFFECTS OF THE MANURIAL AND CROPPING TREATMENTS IN THE AGDELL ROTATION EXPERIMENT

By

R. G. Warren

The Agdell Rotation Experiment was started by Lawes and Gilbert in 1848 and tested two crop rotations and three manurial treatments.

The two cropping schemes were both four-course rotations, one of which was the Norfolk four-course with swedes, barley, clover (or beans) and wheat; the other rotation had the same root and cereal crops, but a fallow replaced the leguminous crop of the Norfolk four-course rotation. The two rotations, side by side, occupied 2½ acres in Agdell Field, on a soil which is one of the heaviest on the Rothamsted farm. The clover, undersown in the barley, failed in some winters, and beans were then sown as a substitute. Although in the early years of the experiment there were more bean than clover crops, the ratio for the whole period was two crops of clover to one of beans.

The manurial treatments were O, P (which was changed to PK in 1884) and NPK; these were put down as three strips across the two rotations. The manures were given once in 4 years and applied to the swede crop only. Part of the nitrogen was supplied as ammonium salts and the remainder as rape cake. Until 1912 the inorganic nitrogen fertilizer consisted of equal parts of ammonium chloride and ammonium sulphate, but afterwards it was given entirely as sulphate. Rape cake was replaced by castor meal in 1940 and in later years. Phosphorus and potassium were supplied as

Table 1

Agdell rotation experiment 1848–1951

Average dressings of manures, cwt./acre, applied every fourth year

Manure	Treatment PK	NPK
Ammonium sulphate	—	2
Rape cake (or castor meal)	—	18
Superphosphate	4	4
Potassium sulphate	3	3½

Supplementary minerals, sodium sulphate at 100 lb./acre and magnesium sulphate at 200 lb./acre, were given whenever potassium sulphate was applied.

superphosphate and potassium sulphate. Throughout the experiment the amount of nitrogen given in each form remained unchanged, but the dressings of superphosphate were increased in 1904

from $3\frac{1}{2}$ to $4\frac{1}{2}$ cwt./acre and those for potassium sulphate from $2\frac{3}{4}$ to $4\frac{1}{2}$ cwt./acre in 1896. The average dressings of the manures are given in Table 1, in which all the inorganic nitrogen has been expressed as ammonium sulphate.

In addition to the comparisons of three manurial treatments on two rotations, Lawes and Gilbert included a test of management when roots were grown. On half of each plot the roots and leaves were carted off; on the other half the produce was eaten on the land by sheep, or, if the weather was unsuitable, the leaves and the roots (after slicing) were spread over the ground. This test was continued until 1900, but in later years the crop was removed from the whole of each of the six plots.

Summary of the Results of the Agdell Experiment

The experiment was continued until 1951, but by then the crops on the NPK plots were affected by soil acidity. The swede crops were generally ruined by clubroot, which first appeared on the acid plots but spread to the other plots. Table 2 gives the average yields of the crops for the first eighteen courses (1848–1919) before the disturbance from soil acidity became serious.

Table 2

Average yields, Agdell Field, 1848–1919

	No manure		PK		NPK	
	Fallow rotation	Clover rotation	Fallow rotation	Clover rotation	Fallow rotation	Clover rotation
Swedes, tons ...	1·7	0·6	8·8	9·6	18·0	15·9
Barley, cwt. ...	11·4	10·8	12·0	12·0	16·4	18·4
Beans, cwt. ...	—	7·7	—	10·7	—	13·1
Clover hay, cwt.	—	30·7	—	58·6	—	60·2
Wheat, cwt. ...	13·8	12·8	16·3	17·7	16·9	17·8

The average results for the eighteen courses show that the two rotations gave similar yields of roots and cereals and that the main advantage of the clover rotation was the extra produce as beans or clover.

In contrast with the effect of crop rotation on yields, there were large responses to the manurial treatments. Nitrogen increased the yields of swedes by 6–9 tons/acre, and on the following crop of barley the residues of the nitrogen manures gave 4–6 cwt./acre more grain; there was, however, no residual effect on wheat, which was the last crop after the application of the nitrogen manures. The PK fertilizer treatment also gave large increases in yields; the increases per acre were for swedes 7–9 tons, clover 30 cwt., beans 3 cwt. and wheat 2·5–5 cwt.

Except for the period of the fed and carted treatments of the swede crop, the whole of each crop in the Agdell Rotation Experiment was removed from the land. While there was no evidence from the crop yields of any accumulation of residues of the nitrogen manures, the wheat crops on the unmanured and PK plots showed that there were residues of the PK fertilizers at the end of the manuring cycle. The response of the wheat crops to residues of these fertilizers provided no estimates of the amounts of phosphorus and

potassium that had accumulated over the whole period of the experiment, nor of the ability of the residues to supply adequate amounts of these nutrients to crops which have higher requirements than wheat.

Effects of the Accumulated Residues of PK Fertilizers

After the conclusion of the Rotation Experiment in 1951 the field was fallowed for 1 year and was then cropped with cereals till 1955. The cereals received only a uniform dressing of nitrogen. During this period a pH survey of the experimental site was made. Serious soil acidity (i.e., pH 5·0–5·5) was found only on the NPK plots, but small areas at the ends of the PK plots which adjoined the NPK plots were either slightly acid or devoid of calcium carbonate. The soils of the remainder of the PK plots and the whole of the unmanured plots contained 2–3 per cent $CaCO_3$. To correct the soil acidity, differential chalk dressings (with a maximum of 5 tons $CaCO_3$/acre for the most acid areas) were applied in the winter of 1953–54. After an interval of 2 years beans and potatoes were grown in successive years to measure the combined effects of the residues of the PK fertilizers applied during the years of the Rotation Experiment. The potatoes received a uniform dressing of nitrogen, but none was given to the beans. The yields were:

Table 3

Effects of the accumulated residues of fertilizers applied in the Agdell rotation experiment

Fertilizer treatment (1848–1951) ...	None		PK		NPK	
Rotation	Fallow	Clover	Fallow	Clover	Fallow	Clover
1956 Beans, grain cwt./acre...	8·5	5·2	26·2	20·0	18·2	19·2
1957 Potatoes, total tubers tons/acre ...	4·4	3·0	14·4	8·6	15·5	14·1
Percentage ware (1½-inch riddle) ...	91	70	95	92	94	92

Good crops of both beans (with yields up to 26 cwt. grain/acre in 1956) and potatoes (up to 15·5 tons/acre in 1957) were grown on the residues of previous manuring. The highest yields were equal to those obtained on other fields of the Rothamsted Farm where 0·6 cwt. P_2O_5 and 1·2 cwt. K_2O/acre was applied to beans and 1·0 cwt. N, 1·0 cwt. P_2O_5 and 1·2 cwt. K_2O together with 12 tons farmyard manure/acre was given to potatoes. Both crops on Agdell showed large increases in yield due to the residues of phosphorus and potassium in the soils of the PK and NPK plots. For beans the average increase was 14 cwt. of grain/acre, and for potatoes 8·5 tons of tubers/acre. These increases are the combined effects of phosphorus and potassium residues, but the design of the original experiment does not make it possible to separate the effects of the two nutrients. In seven of the eight comparisons between the rotation with fallow and the rotation with clover the latter gave lower yields in the residual years. Even on the unmanured plot, the extra crops (taken as clover or beans) on the clover section have further ex-

hausted the levels of phosphorus and potassium in the soil, which were already very low. In addition to lowering the yields of beans and potatoes by 3 cwt. and 1 ton/acre respectively, the further soil exhaustion caused by the clover crops reduced the proportion of ware potatoes from 90 to 70 per cent. An indication of the cause of the large increase in the proportion of small tubers is given by the phosphorus and potassium composition of the tubers from the fallow and clover sections. The percentages of potassium in the potatoes from the two sections were almost identical, but the crop from the clover section had a much lower phosphorus content. The values were:

	Percentage in dry matter	
	P	K
Unmanured plot:		
Fallow rotation	0·149	1·26
Clover rotation	0·114	1·30

It seems probable, therefore, that although the available phosphorus and potassium in the soil were both very low as a result of cropping for a hundred years without manure, the phosphorus shortage was more acute than the potassium shortage on the clover section, and was mainly responsible for the lower yield and the large reduction in percentage of ware potatoes.

The PK residues in the soil have increased both the percentages of phosphorus and potassium in the crops and also the yields, and the two effects have accentuated the differences in the uptakes of both nutrients on the unmanured and the fertilizer plots. The results are given in Table 4.

TABLE 4

Phosphorus and Potassium Contents of Potatoes, Agdell Field 1957

	Fertilizer treatment 1848–1951 every 4 years					
	O		PK		NPK	
Rotation	Percentage in dry matter					
	P	K	P	K	P	K
Fallow ...	0·149	1·26	0·206	1·75	0·197	1·87
Clover... ...	0·114	1·30	0·180	1·41	0·186	1·50
	Total nutrients in crops, lb./acre					
Fallow ...	3	24	13	110	13	119
Clover... ...	2	18	7	54	12	96
	Gain from fertilizer residues, lb./acre					
Fallow ...	—	—	10	86	10	95
Clover... ...	—	—	5	36	10	78

The percentages of the two nutrients in the potatoes illustrate the high demand made by this crop for potassium relative to phosphorus. The residues of the PK fertilizers have increased the concentration of phosphorus by one-half and potassium by one-quarter of the values in the crops of the unmanured plots. These increases, together with those in yields of tubers, amount to 5–10 lb. extra P and 36–95 lb. extra K/acre in the crops grown on the residues, and provide evidence additional to that obtained from the Exhaustion Land Experiment on the availability of both phosphorus and potassium accumulated in soils from applications of fertilizers over a long period.

In the Exhaustion Land Experiment the value of the residues was established only for barley, but even for this crop the experiment supplied no information, by direct measurement, on the adequacy of the PK residues for growing maximum crops, nor on the separate effects of the two nutrients. From the yields of barley and the crop composition it was possible to deduce that the yields were governed mainly by the phosphorus supplies in the soil and that, for these amounts, the potassium residues were more than sufficient. A 2-year scheme of modified cropping and manuring was started in 1957 on part of the Exhaustion Land to give a more complete assessment of the residues. Six crops, barley, wheat, potatoes, sugar beet, swedes and kale are being grown side-by-side, and new dressings of P and K fertilizers have been applied to establish phosphorus and potassium response curves by which to measure the individual nutrient effects of the residues. During the period 1856–1900 wheat was grown for the first 20 years on the site now known as the Exhaustion Land, and potatoes in the remaining years. The average annual dressings of P and K fertilizers were 3 cwt. of superphosphate and 2·5 cwt. of potassium sulphate/acre. The accumulation of fertilizer residues in the soil has therefore occurred under conditions which were abnormal but were favourable to the build-up, for wheat is one of the less-exhausting crops, and the rate of manuring was high. The potatoes, although they have a much higher nutrient requirement, did not yield well.

The results from the Agdell Experiment have a greater interest, since the conditions were nearer normal farming practice. The cropping system followed was a Norfolk four-course rotation, and the manuring was not excessive. PK fertilizers were applied to the roots every fourth year, and were equal to 1 cwt. of superphosphate and 1 cwt. of potassium sulphate/acre for each of the hundred years of the experiment. The uptakes of phosphorus and potassium by the crops of the first eight courses were determined by Lawes and Gilbert. The average yields for the eighteen courses up to 1919 differed little from those for the first eight courses, but by 1930 the crops on the NPK plot were affected by soil acidity. Up to 1919 therefore the estimated average excesses of added fertilizer phosphorus and potassium over the amounts of the two nutrients withdrawn by the crops on the fallow and clover sections of the PK and NPK plots were per year:

Fertilizer treatment	PK		NPK	
	P	K	P	K
	lb./acre			
Rotation with fallow	5	15	8	20
Rotation with clover	3	7	5	10

The higher annual excess of phosphorus on the NPK plot arises from the phosphorus contained in the rape cake applied to this plot, while the higher potassium is due in part to the same cause and in part to the absence of K fertilizer applications on the PK plot for the first 32 years of the experiment. If these excesses have accumulated in the soil in an available form during the past hundred years there would be sufficient phosphorus and potassium for a further ten courses of the rotation.

The Agdell Soils

Nitrogen

The manuring and cropping treatments have produced marked differences in the nitrogen, phosphorus and potassium contents of the soils. In Table 5 the total nitrogen contents are given of soil samples taken on three occasions, two during the course of the experiment and the third in 1953, 2 years after it had ended.

Table 5

Total nitrogen, as percentage of surface soil (0–9 inches)

	Treatment					
	O		PK		NPK	
Year	Fallow rotation	Clover rotation	Fallow rotation	Clover rotation	Fallow rotation	Clover rotation
1867	0·127	0·130	0·123	0·135	0 129	0·130
1913	0·118	0·141	0·122	0·148	0·127	0·147
1953	0·119	0·152	0 121	0·152	0·118	0·144

On the soils of the fallow rotation the effects of time and manuring are in accordance with those shown by the Broadbalk plots with similar fertilizer treatments (Warren, R. G. 1956: *Proc. Fert. Soc.* 37). The levels of nitrogen on both the unmanured and the PK plots had fallen by 1913 to the same value, 0·12 per cent N (which is a little higher than on Broadbalk) and had not changed during the next 40 years. For the NPK plot there was a small increase over the other two plots, as on Broadbalk, due to the extra nitrogen in the greater plant residues. Unlike the Broadbalk soil, however, the increase in nitrogen of the Agdell NPK plot was not maintained, and by 1953 the level had fallen to that of the unmanured plot. This decrease may possibly be due to the development of soil acidity on the NPK plot, which affected yields after 1930. The explanation must remain in doubt, since weed growth in the cereal crops increased rapidly as the soil became acid and the crop yields fell. No figures are available to show whether the amount of weed growth below the cutter-bar of the binder was less than the amount of plant residues that would be ploughed in after harvesting a good clean crop.

The greatest effect shown by the figures in Table 5 arose from the replacement of fallow by clover, which increased the nitrogen content of the soil by 0·03 per cent. This increase occurred on both manured and unmanured plots, and it is surprising that the soil of the unmanured plot of the clover rotation had increased in nitrogen as much as the soil of the PK and NPK plots in the same rotation. With lower yields on the unmanured plot, and especially of clover, the smaller amounts of crop residues would return less nitrogen to the soil than residues on the manured plots. The records of the Agdell experiment mention frequently the abundance of weeds on the unmanured plot, but, though the weeds would undoubtedly help to conserve soil nitrogen, the source of the additional nitrogen to compensate for the smaller residues of the clover crops is unknown, since the weeds were predominantly non-leguminous.

The extra nitrogen in the soils of the clover rotation towards the end of the experiment as compared with those of the fallow rotation,

was about 600 lb./acre, but its rate of mineralization to produce inorganic nitrogen for subsequent crops was small. This is illustrated by the yields of the plots which received phosphorus and potassium but no nitrogen fertilizers. Such data provide the only estimate in this experiment of the availability of the accumulated soil nitrogen. The average yields of barley and the mean total nitrogen contents of the soils for the later years of the experiment were:

	PK plots	
	Fallow rotation	Clover rotation
Barley, grain cwt./acre, mean of 10 seasons, 1913–51	10·5	11·6
N per cent in soil, mean of 1913 and 1953 samples ...	0·12	0·15

The results support the conclusion drawn from the Hoosfield Barley Experiment that, at a level of 0·15 per cent N in the soil, the extra amount of old organic matter residues above the amount in a starved soil provides but little nitrogen for barley. However, further tests of the value of the extra organic nitrogen are needed with other crops, especially with those which would benefit from the nitrogen that is mineralized in the autumn.

Phosphorus and potassium

The phosphorus and potassium analyses of the soil samples taken in 1913 and 1953 reflect the manurial treatments, type of rotation, the carting of roots versus the " feeding " of roots on the plots and also the effect on yield of the more acute soil acidity of the NPK plot of the clover rotation.

Although the comparison of carting versus feeding of roots ceased after 1900, the effect (as measured by soil analysis) on the potassium returned to the land on the " fed " portions of the PK and NPK plots was still detectable in the soil samples taken in 1913. The feeding, compared with carting, gave an average increase of 3 mg. readily soluble K/100 g. soil, the amounts being greater on the fallow rotation and less on the clover rotation. This extra potassium had been reduced to negligible quantities by 1953. The two rotation sections of the unmanured plot showed no differences in soluble potassium on either sampling date, nor were there any differences in the effects of the carting and feeding treatments on the nitrogen and phosphorus contents of any of the plots on these occasions.

The changes in phosphorus and potassium contents of the soils due to manuring and crop rotation are set out in Table 6 for the 1913 and 1953 samples, after averaging the results for the carting and feeding sections of the plots.

The moderate dressings of PK fertilizers that were applied in this experiment have increased the readily soluble phosphorus and potassium in the soils, especially of the fallow rotation. By taking a crop of clover or beans once in 4 years instead of a fallow the supplies of these two nutrients were greatly reduced. On all the fertilizer plots, except the PK plot in the clover rotation, the differences over the unmanured plot which were built up in the earlier years continued to increase, and by 1953 the highest values for soluble P and K attained (and especially for potassium) would be

regarded as adequate for crops other than those having a very high requirement, such as potatoes and sugar beet. On the PK clover rotation plot, unlike the other fertilizer plots, the levels of soluble phosphorus and potassium have remained unchanged during the last 40 years. This difference in behaviour, especially as compared with the NPK clover rotation plot, would appear to indicate some abnormality in the PK plot. It is more probable, however, that the NPK clover plot is the discordant one, owing to the onset of soil acidity during the years 1913–53, which led to lower crop yields and uptakes of nutrients, and consequently to greater phosphorus and potassium residues in the soil.

TABLE 6

Phosphorus and potassium in the Agdell soils 1913 and 1953

Fertilizer Treatment...	O		PK		NPK	
Rotation: fallow (f), clover (c)	f	c	f	c	f	c
	P soluble in 0·5*M*-$NaHCO_3$, mg./100 g.					
1913	0·25	0·20	1·05	0·55	1·00	0·55
1953	0·30	0·20	1·35	0·55	1·15	0·75
	K soluble in 0·5*N*-HAc, mg./100 g.					
1913	8·5	8·5	17·0	13·0	15·5	11·5
1953	9·0	9·0	20·5	14·0	20·0	17·0

The acidity of the clover and fallow parts of the NPK plot, though an unfortunate development for the main objects of the Agdell experiment, has provided some information on the availability of phosphorus in the soil derived from applications of superphosphate given before and during the period of acidity. The clover section was the more acid at the conclusion of the experiment, with about half the area at pH 4·8–5·0 and the remainder at pH 5·2, while the soil of the fallow part was almost entirely within the range pH 5·4–5·6. The chalking carried out in the winter of 1953–54 raised the values to a little above pH 7. In 1956 and 1957, when beans and potatoes were grown to measure the residual values of the PK fertilizers, the yields were good and similar to those on the PK plot, which had not developed acidity. The uptakes of phosphorus given in Table 4 were almost identical for the fallow sections of the two plots, while for the clover sections the amount of phosphorus in the potato crop of the NPK plot which had been acid was greater than that of the PK plot. Although no comment can be made on the state of the phosphorus during the period of soil acidity, the results of the potato crop show that after bringing the soil to pH 7 the availability of the phosphorus residues was at least equal to that of the residues in the soil which had not been acid.

The yields and nutrient contents of the potato crop in 1957 and the soil analyses have established two facts: first, that residues of PK fertilizers have accumulated, and secondly that these residues are available. However, the three types of figures, taken singly or collectively, do not give quantitative estimates of the reserves built up in the soil by the fertilizers. To obtain this information half of each plot will be sown with a crop able to exhaust the soil rapidly, such as grass cut for silage, to which adequate nitrogen

fertilizer will be given. The value of PK fertilizer residues for a wider variety of crops will continue to be tested in the Exhaustion Land Experiment. As the manuring and cropping treatments of the Agdell experiment have produced a set of soils with different phosphorus and potassium contents, the halves of the plots not put down to grass will be used for a more precise standardization of methods of soil analysis. The Agdell series is much more suitable for this purpose than the series on the Exhaustion Land, where the levels of nutrients are generally either "low" or "medium". With the additional information that would be obtained from this extension of work suggested for Agdell Field, soil analysis could profitably be used more frequently for avoiding the accumulation of fertilizer residues to an unnecessary degree and (of equal importance) to prevent a gradual exhaustion of the soil.

PUBLICATIONS

Physics Department

1.1. EMERSON, W. W. (1957). Organo-clay complexes. *Nature, Lond.* **180**, 48–49.

1.2. LONG, I. F. (1958). Some observations on dew. *Met. Mag.* (In the press.)

The difference between dew, fog precipitation and guttation on a grass cover is described along with a short review of the measurement of dew. The source of dew, whether from distillation of water vapour from the ground or " dewfall " from the nocturnal inversion of the atmospheric vapour pressure gradient, is shown to be influenced by the type of crop cover, its height and density. Evidence is given that dew may occur but not persist until 0900 hours when routine weather observations are taken, so leading to underestimates in reports of the frequency of its occurrence.

1.3. MONTEITH, J. L. (1957). Dew. *Quart. J. R. met. Soc.* **83**, 322–341.

Dew formation on short grass has been studied with a balance, recording weight of condensation, and with filter-papers to absorb moisture. Three regimes are distinguished: in the first, daytime evaporation continues and the grass remains dry; in the second, the surface continues to lose weight, but the grass becomes wet owing to the partial condensation of water vapour evaporating from the soil; in the third, this loss of weight ceases or there is an increase in weight attributed to condensation of atmospheric water vapour. A distinction is therefore made between " distillation " of water vapour from soil to grass (1–2 mg. cm.$^{-2}$ hour^{-1}) occurring on very calm nights through a laminar layer with a transfer coefficient approaching the molecular value; and " dewfall ", the turbulent transfer of water vapour from the atmosphere, negligible when the wind at 2 m. falls below 0·5 m./second, but reaching 3 4 mg. cm.$^{-2}$ hour^{-1} with stronger winds. This distinction is supported by analysis of the surface heat-budget. On windless nights, since heat flux from the soil and net radiative loss were almost equal, the transfers of sensible and latent heat from the atmosphere were negligible, and distillation was of much greater importance than dewfall. Implications for taller crops and warmer climates are briefly considered.

1.4. MONTEITH, J. L. (1957). Climatology in arid zone research. *Weather*, **12**, 203–210.

A review of a United Nations Educational Scientific and Cultural Organization symposium held in Australia is given. Subject headings are: water relations of plants; water relations of animals; measurement of evaporation; estimation of evaporation from climatic data; measurement of rainfall and dew; modifying the water balance; temperature relations of plants and animals; heat balance; modifying the heat balance; light; and the scope of climatology.

1.5. PENMAN, H. L. (1957). Hill climate. *Nature, Lond.* **180**, 574–576.

1.6. PENMAN, H. L. (1958). Water control for increased crop production. In *The Biological Productivity of Britain* (Inst. of Biology, London).

Drainage. There is need for more research on the responses of different types of crop to different depths of water-table. Surface drainage systems on the clay lands of south-east England need renewal over about half the area. On the hill land of the north and west, about half needs a drainage system, and half of this has been done.

Irrigation. It is possible to specify which areas of Britain might benefit from supplementary irrigation, and experimental work within these areas is

showing that grass and potato yields are increased in most summers, sugar-beet yields in some and cereal yields occasionally.

1.7. Russell, E. W. (1957). The effects of very deep ploughing and of subsoiling on crop yields. *J. agric. Sci.* **48**, 129–144.

1. Deep tillage, namely, ploughing to a depth exceeding 12 inches, or subsoiling to a depth of about 18 inches, increased crop yields on about half the fields in which an experiment was made. Unfortunately, it was not possible to recognize what was the difference in soil properties between the 50 per cent of fields that responded appreciably to deep tillage and the remainder, whose yields were either unaffected or sometimes reduced by deep tillage, though, as one would expect, sands were normally less responsive to deep tillage than the heavier soils.

2. On the clay soils deep ploughing in autumn tended to give a surface soil that dried out up to several weeks earlier in the spring than land that was shallow ploughed. Subsoiling did not cause the surface soil to dry out in the same way. Only rarely did the subsoil brought up by deep ploughing give difficulty in working down to a seedbed, and probably in as high a proportion of fields the subsoil worked easier than the surface soil.

3. On the clays and loams the response of potatoes to deep tillage was more marked on fields that were heavily manured than on those lightly manured.

4. Sugar beet normally gave a higher yield if its potash and phosphate was spread on the land before ploughing, even if this was in the autumn, than if it was applied in the seedbed. The exceptions to this result were for soils heavier than sandy loams if ploughing depths exceeding 12 inches were used, for the yield of beet was, on the average, depressed on these soils if the potash and phosphate was ploughed in compared with it being worked into the seedbed.

5. Deep ploughing tended to give better control of many perennial weeds, and often of annual weeds than shallow ploughing. It is suggested that much of this benefit could be obtained when ploughing to 9–10 inches deep if ploughs were used that cut a furrow considerably wider than the conventional 10½–11-inch furrow, so allowing more complete inversion of the furrow slice.

Chemistry Department

General Papers

2.1. Cooke, G. W. (1956). Soils and fertilizers. *J. R. agric. Soc.* **117**, 113–129.

2.2. Cooke, G. W. (1957). Soils and fertilizers. *J. R. agric. Soc.* **118**, 131–146.

2.3. Cooke, G. W. (1957). The value of fertilizer placement. *J. R. agric. Soc.* **118**, 37–49.

A summary of recent fertilizer placement research carried out in this country. The value of placement for common crops is stated, and the factors affecting the use of the method are discussed.

2.4. Haines, W. B. (1958). On the cyclic recurrence of peak yields in the individual palm. *Oléagineux*. (In the press.)

2.5. Mattingly, G. E. G. (1957). The use of the isotope ^{32}P in recent work on soil and fertilizer phosphorus. *Soils & Fert.* **20**, 59–68.

A detailed review of some of the uses of ^{32}P-labelled orthophosphate in laboratory and greenhouse experiments during the past few years. The following problems are discussed:

Properties of calcium, iron and aluminium phosphates.
Adsorption and exchange of phosphate on resins, clays and $CaCO_3$.
Isotopic exchange of phosphates in soil.
Uptake of phosphorus from ^{32}P-labelled fertilizers.
Diffusion and movement of phosphate in soil.
Phosphate residues in soil.

2.6. Mattingly, G. E. G. (1957). The agricultural value of sewage sludge and town refuse. *Proc. Instn Civ. Engrs*, **8**, 414–420.

The paper gives a brief description of sewage sludges and town wastes, their chemical compositions and estimates of their values as organic manures from field experiments.

2.7. Talibudeen, O. (1957). Nutrient availability. *Soils & Fert.* **20**, 189–190.

Research Papers

2.8. Bremner, J. M. & Shaw, K. (1958). Denitrification in soil. I. Methods of investigation. *J. agric. Sci.* (In the press.)

Methods of investigating denitrification in soil are critically discussed with special reference to methods based on total-N analysis. A modified Kjeldahl method of determining nitrogen which includes nitrate and nitrite and is applicable to waterlogged soil is described, and the use of this method in studies on denitrification in soil is illustrated and discussed. Rapid denitrification of nitrate in soil can be induced by incubating the soil under waterlogged conditions with organic materials such as glucose, and denitrification can be followed by total-N analyses if the organic material used to induce denitrification is not added in such excess that it also promotes significant fixation of atmospheric nitrogen. The percentage of added nitrate-N lost by denitrification on incubation of waterlogged soils with different amounts of nitrate and sufficient glucose for denitrification was the same whatever the level of application of nitrate. Denitrification of nitrate in waterlogged soil containing glucose was accompanied by a rapid but temporary accumulation of large quantities of nitrite and by the formation of smaller amounts of ammonia. Hydroxylamine could not be detected during denitrification, but this compound was rapidly decomposed in the soils examined by a process which appeared to be purely chemical. Denitrification of nitrate in soil is a microbiological process, and the viability of the micro-organisms responsible for denitrification is not affected by air-drying and storage of the soil.

2.9. Bremner, J. M. & Shaw, K. (1958). Denitrification in soil. II. Factors affecting denitrification. *J. agric. Sci.* (In the press.)

The factors affecting denitrification in soil were studied by determining loss of nitrogen from soil under various conditions by total-N analysis. The rate of denitrification of nitrate in soil was dependent upon various factors such as pH, temperature and water content of the soil. Under conditions conducive to denitrification 80–86 per cent of nitrate-N added to Rothamsted soils was lost by denitrification in 5 days. Rate of denitrification was greatly affected by soil pH. It was very slow at low pH (below 4·8), increased with rise in soil pH and was very rapid at pH 8·0–8·6. The rate of denitrification increased rapidly with rise in temperature from 2° to 25°; the optimum temperature being about 60°. The degree of water saturation of the soil affected the rate of denitrification profoundly. Below a certain moisture level practically no denitrification occurred; above this level denitrification increased rapidly with increase in moisture content. The critical moisture level was about 60 per cent of the water-holding capacity of the soil. No loss of nitrogen by denitrification could be detected when moist soils were incubated with or without nitrate and glucose and were aerated continuously during incubation. The rate of denitrification in soil depended upon the amount and type of organic material present. The results obtained support the view that denitrification occurs only when the supply of oxygen required by the soil micro-organisms is restricted.

2.10. Cooke, G. W. & Cunningham, R. K. (1958). Investigations on soil nitrogen. Part III. Mineralisable nitrogen determined by an incubation technique. *J. Sci. Fd Agric.* (In the press.)

" Mineralisable-N " values were determined by incubating a series of 27 soils of medium and heavy textures at 50 per cent of their moisture-holding capacity and at 18° for 30 days. Increases in nitrate levels following incubation of soils which had been air-dried beforehand were, on average, three

times as great as increases given by incubating corresponding freshly-sampled soils. In all soils the levels of nitrate and total mineral nitrogen increased appreciably on incubation; corresponding changes in ammonium levels were smaller, they were also irregular and were not related to other soil characteristics. Increases in nitrate and in total inorganic nitrogen on incubating air-dried soils were approximately related to the initial levels of nitrate present in the soils when they were sampled, and to their percentages of total nitrogen.

2.11. Cunningham, R. K. & Cooke, G. W. (1958). Investigations on soil nitrogen. Part II. Changes in levels of inorganic nitrogen in a clay–loam soil caused by fertilizer additions, by leaching, and uptake by grass. *J. Sci. Fd Agric.* (In the press.)

Concentrations of nitrate and ammonium in both the surface (0–9 inches) and the subsoil (9–18 inches) of a heavy clay-loam were determined at intervals both on uncropped soil and under ryegrass. On uncropped land high levels of nitrate were maintained through wet periods, which caused percolation through 20 inches of bare soil. Only persistent and heavy rainfall in late summer reduced surface-soil nitrate to low levels. Ammonium provided by ammonium sulphate or by decomposition of urea was converted to nitrate quite slowly, and the soil contained equal amounts of ammonium and nitrate in July. No ammonium was transported into the subsoil. Little total mineral nitrogen was lost from the top-soil of uncropped land during June and July, but during August and September nitrate concentrations in the subsoil increased rapidly. Total inorganic nitrogen in the top 18 inches of soil remained roughly constant until the end of July, afterwards there was a loss of nitrogen from the profile as a whole. On unmanured plots fluctuations in ammonium levels were much smaller than corresponding changes in nitrate.

Under grass soil nitrate levels fell quickly in warm wet weather when growth was rapid. In the same period on plots receiving ammonium sulphate or urea, grass removed ammonium quickly, and there was no increase in soil nitrate. When a first cut of grass was taken in July four-fifths of the total supply of nitrate or ammonium present in the soil at the beginning of the experiment had been removed. While the second crop was growing there was little nitrate (or ammonium) in the surface soil, but the harvested grass "recovered" as much of the applied nitrogen as the first crop. It is suggested that nitrogen used in growth by the second crop was either taken up earlier and stored in the plant or that it was taken from the subsoil.

2.12. Cooke, G. W., Mattingly, G. E. G. & Widdowson, F. V. (1958). The value of nitrophosphate fertilizers. *J. agric. Sci.* (In the press.)

The phosphorus effects of several nitrophosphates were compared with those of superphosphate and dicalcium phosphate in field experiments in 1954 and 1955. In both years immediate effects were measured on radishes, and in 1954 residual effects were measured on a crop of ryegrass which was cut twice.

None of the nitrophosphates tested was more than one-third as efficient as superphosphate for radishes. The residual effects of nitrophosphates (relative to superphosphate) for grass were much larger than their corresponding immediate effects on radish; several materials were as good as superphosphate for increasing the yields of the second cut of grass. The immediate effects of nitrophosphates were much increased by preparing finely ground powders from commercial granulated products.

In both years dicalcium phosphate was equivalent to superphosphate and gave significantly higher yields of radish than any of the granulated nitrophosphates. At the second cutting of grass in the 1954 experiment there were no significant differences between yields given by dicalcium phosphate and the nitrophosphates.

The solubilities of the phosphorus of nitrophosphates in solutions of citric acid, neutral ammonium citrate and alkaline ammonium citrate were of little value in estimating immediate effects of granulated products. It is suggested that physical properties of the granules affect the rate at which phosphate ions can diffuse and so complicate the interpretation of solubility tests.

2.13. Cooke, G. W., Mattingly, G. E. G. & Williams, R. J. B. (1958). Changes in the soil of a long-continued field experiment at Saxmundham in Suffolk. *J. Soil Sci.* (In the press.)

A four-course rotation experiment was carried out at Saxmundham on wheat, mangolds, barley and legumes. Yields of all crops were much increased by phosphate fertilizers; nitrogen fertilizers increased yields of non-legumes; extra yields from potash fertilizers were smaller. Fifty-six years of continuous manuring caused the following changes in the calcareous boulder clay soil: plots receiving farmyard manure contained half as much again organic carbon as plots receiving fertilizers, plots receiving N and P fertilizers contained slightly more organic matter than plots without these fertilizers. Total soil nitrogen was considerably increased by farmyard manure and was slightly higher on plots receiving sodium nitrate than on plots without nitrogen fertilizer. Total soil phosphorus was built up by farmyard manure and by bone meal, and to a smaller extent by light annual dressings of superphosphate. "Soluble phosphorus" determined by three methods differentiated clearly between plots which had received phosphate fertilizers and those which had received none. An accumulation of bone-meal residues was demonstrated by dilute hydrochloric acid extraction, but not by methods involving extraction with 0·5*M*-sodium bicarbonate or equilibrium with 0·01*M*-calcium chloride. Soluble-phosphorus values by all three methods indicated the presence of fertilizer residues more clearly than did values for total soil phosphorus. The soil contained a large quantity of total potassium, and the values were not materially affected by manuring. Dilute HCl soluble-K and exchangeable-K values differentiated between plots which had received potash fertilizers and those which had received none. They also reflected changes in soluble potassium caused by the different amounts of potassium removed in the crops grown.

2.14. Haines, W. B. (1958). On the significance of cyclic peak yields in Nigerian oil palms. *Emp. J. exp. Agric.* (In the press.)

Examination of the yields of individual oil palms in Nigeria (provided from the records of manuring experiments) has established the existence of a very interesting and important rhythmic behaviour. Peak yields occur with very considerable regularity every third or fourth year in almost all palms. In between these good years the yield is often very poor, or may fail altogether. The peak year is shown to be expected from considerations of the sexual cycles in the flowers and the rate of their appearance with emerging fronds. The difference between good and bad years must therefore be regarded as losses, and it is of such magnitude that a restoration of the bad years to normal would increase average crops by 74 per cent. Arguments are adduced for considering that the yield reductions are not due to inevitable physiological reaction to the strain of the good years.

The explanation advanced is that the natural palm rhythm is of a shorter period than the annual weather cycle. The female or fruiting cycle recurs on the average every 9 months. The peak year is supposed to be the result of a propitious conjunction between weather and the phases of development of the fruit, so avoiding abortions. Then in the next year the relationship moves and must have some adverse conjunction which reduces the crop. The propitious year would recur every third year as a "beat" between a 9-month palm cycle and a 12-month weather cycle. The particular nature of the sensitive phases in the palm upon which such a mechanism depends (such as certain weather conditions needed during pollination) have still to be defined. It is clear that there is great possibility of rewards if the sensitive phases prove capable of recognition and correction by established field treatments (such as spraying).

2.15. Mattingly, G. E. G. & Widdowson, F. V. (1958). Uptake of phosphorus from ^{32}P-labelled superphosphate by field crops. Part I. Effects of simultaneous application of non-radioactive phosphate fertilizers. *Plant & Soil.* (In the press.)

Results from nine field experiments carried out in 1952, 1953 and 1954 on contrasting sites at Rothamsted are described. The effects of the simultaneous application of non-radioactive fertilizers (superphosphate, dicalcium

phosphate and Gafsa rock phosphate) on yield, total phosphorus uptake and uptake of radioactive superphosphate drilled with the seed for barley, and near the seed for fodder beet, are discussed, with reference to the influence of soil conditions and the weather.

The amounts of phosphorus taken up from superphosphate drilled near the seed of barley or root crops were almost independent of the simultaneous application of normal agricultural dressings of other phosphate fertilizers applied broadcast. Uptake increased with time from sowing (with one exception), and the total amount of labelled fertilizer recovered in the crops at harvest varied both with the season and with the site of the experiment. In general, less fertilizer was utilized on soils of high phosphate status, particularly in years when crops grew slowly.

"Superphosphate equivalents" of the broadcast non-radioactive phosphate fertilizers were estimated in terms of placed radioactive superphosphate as a standard by measuring the increase in labile or isotopically-exchangeable phosphorus in the soil from single dressings of broadcast phosphate fertilizers. Results obtained by this method confirmed that drilled applications of superphosphate were more effective than broadcasting for barley and that the two methods of application were equivalent for fodder beet.

2.16. Talibudeen, O. (1958). Isotopically exchangeable phosphorus in soils. III. The fractionation of soil phosphorus. *J. Soil Sci.* **9**, 131–140.

Phosphate residues in the soil were subdivided into three fractions on the basis of isotopic exchange of orthophosphate ions between the soil and the soil solution. It was observed that the total labile phosphorus was a smaller fraction of the total phosphorus in the heavier soils (*ca.* 20 per cent clay) than in the lighter soils (1–10 per cent clay). This could be partly attributed to a higher organic-phosphorus content in the heavier soils. In comparable soils, recent manuring with superphosphate increased the ratio of the rapidly labile phosphate to the total labile phosphate; in the soils of lower clay content this ratio was higher than the corresponding ratios in the heavier soils. The recovery of phosphorus added at a moderately heavy rate was estimated by this method of fractionation in soils incubated for periods up to 3 months after treatment. Recovery of added phosphorus in the total labile fraction was incomplete for the calcareous soils, as compared to a 100 per cent recovery in a neutral soil of similar clay content. Moreover, a redistribution of phosphorus with time was observed in the calcareous soils *within* the total labile fraction, no such effect being observed with the neutral soil. This was attributed to the presence of internal surfaces on the calcium carbonate present.

2.17. Warren, R. G., Cooke, E. H. & Cooke, G. W. (1958). Field experiments on concentrated organic nitrogen fertilizers. *J. agric. Sci.* (In the press.)

Hoof, formalized hoof, formalized casein, leather wastes and dried blood were compared with ammonium sulphate for vegetables in several field experiments which were continued for a number of years. Residual effects were measured on grass in one experiment at Rothamsted.

For crops which had a high requirement for nitrogen, hoof and formalized casein tended to give somewhat lower yields than equivalent ammonium sulphate. Organic nitrogen fertilizers tended to be slightly superior to ammonium sulphate for less responsive crops and also in experiments where the high rate of ammonium sulphate gave lower yields than the medium rate.

Crushed hoof and a formalized casein product gave similar yields of most crops. There were no marked gains from treating hoof with formalin; a coarse (5–7-mm.) sample of formalized casein did not give materially different yields from the ordinary fine (2-mm.) product.

One leather product made by simple roasting was inferior to ammonium sulphate and to hoof. Other leather wastes processed by alkalis did not behave very differently from crushed hoof or from ammonium sulphate. Dried blood was tested in a few experiments; there were no significant differences between yields given by blood and by ammonium sulphate.

In experiments on light soil spring cabbages planted in autumn were very sensitive to the time of applying nitrogen fertilizer; there were much larger

gains in yield from ammonium sulphate applied half at planting and half in spring than from either ammonium sulphate or organic nitrogen fertilizers applied wholly at planting.

Plots which had received either organic nitrogen fertilizers or ammonium sulphate continued to give significantly larger yields of grass than untreated plots for several years after manuring was stopped. The apparent " residual effects " of organic nitrogen fertilizers were similar to those of ammonium sulphate. Residues of formalized hoof gave slightly larger yields than residues of untreated hoof. Coarse formalized casein did not have appreciably larger residual effects than the fine material.

There were only small changes in the nitrogen contents of the soils of the plots at Rothamsted during the 10 years when fertilizers were applied. Soil nitrogen decreased on plots receiving no nitrogen fertilizer; hoof, formalized casein and ammonium sulphate dressings maintained soil nitrogen at its original level, and there was a slight increase where formalized hoof had been applied for a number of years.

2.18. Widdowson, F. V. & Cooke, G. W. (1958). Nitrogen fertilizers for spring barley and wheat. *J. agric. Sci.* (In the press.)

Ten experiments on spring barley (mainly Proctor) and four on spring wheat (mainly Atle) in 1954–56 compared 0·25 and 0·5 cwt. N/acre (as ammonium sulphate) when drilled with the seed with dressings broadcast before sowing. Tests were also made of " Nitro-Chalk " dressings given in mid-May. In heavier split applications seedbed dressings were supplemented by top-dressings of 0·5 cwt. N/acre.

Barley gave much larger average responses than wheat. For barley combine-drilling 0·25 or 0·5 cwt. N/acre gave consistently larger yields than broadcasting the same nitrogen dressing on the seedbed; for wheat combine-drilling gave slightly higher yields at the high rate of dressing only.

For both crops 0·5 cwt./acre of N drilled with the seed was almost sufficient for maximum yields, but where only 0·25 cwt. N was applied at sowing a mid-May top-dressing of 0·5 cwt. N/acre gave higher yields.

At most centres May top-dressings of " Nitro-Chalk " gave lower yields than equivalent ammonium sulphate drilled with the seed. Yields were often reduced by lodging on plots which received seedbed-dressings plus top-dressing or the heavier rates of top-dressing alone; these treatments also reduced the quality of the grain. Combine-drilled or broadcast seedbed dressings did not cause serious lodging or reduce grain quality.

0·25 cwt. or 0·5 cwt. N/acre broadcast on the seedbed or combine-drilled had little effect on the percentage of nitrogen in the grain; equivalent top-dressings in mid-May consistently increased nitrogen content. Seedbed dressings plus top-dressings supplying heavier total quantities of nitrogen continued to increase nitrogen percentage in grain without giving any increase in yield.

On average about one-third of dressings supplying 0·5 cwt. N/acre was recovered in barley grain; wheat grain recovered only about one-eighth of the nitrogen applied. Percentage recoveries of nitrogen from heavy dressings applied partly on the seedbed and partly as top-dressings were rather smaller.

2.19. Widdowson, F. V. & Cooke, G. W. (1958). Comparisons between placing and broadcasting of nitrogen, phosphorus and potassium fertilizers for potatoes, peas, beans, kale and maize. *J. agric. Sci.* (In the press.)

In eight experiments on main-crop potatoes in 1953–54 placing 0·5 cwt. N/acre in a band beside the seed tended to give higher yields than broadcasting the dressing; when 1·0 cwt. N/acre was applied, broadcasting tended to be superior to placement. There were no consistent gains from placing 1·5 cwt. K_2O/acre.

Four other potato experiments in 1954–56 tested all combinations of placing and broadcasting two levels of nitrogen and potassium. There was no clear relationship between the effects of broadcasting or placing one nutrient and the way in which the other nutrient was applied. When 0·5 cwt. of N was applied, placing gave higher yields in seven out of ten possible comparisons (one effect was significant). With 1·0 cwt. N/acre there were also seven of ten comparisons in favour of placement (three significant effects), but in two

other comparisons broadcasting gave significantly higher yields. Placing potassium gave higher yields than broadcasting in sixteen out of twenty comparisons (six significant effects), in one of the remaining comparisons broadcasting potassium was significantly superior. Placing of the potassium and, to a lesser extent, the nitrogen components of a complete potato fertilizer is likely to be beneficial.

In two experiments, each on green peas and broad beans, placing of phosphorus and potassium separately and together gave consistently higher yields than broadcasting these nutrients. When nitrogen was used in addition to phosphorus and potassium there were small gains in yield of broad beans provided the mixture was placed. There were no gains in yields of green peas from nitrogen, however the mixture was applied.

In one kale experiment in 1955 there were no significant effects on yield. In a 1956 experiment placing P, PK and NPK fertilizers beside the seed gave higher yields of kale than broadcasting these fertilizers.

In one maize experiment in 1956 the crop did not ripen properly. All nitrogen dressings delayed maturity, and where nitrogen was placed (with or without potassium) it gave significantly less crop than broadcasting.

Book

2.20. Cooke, G. W. (1958). Contribution to: *The Agricultural Notebook*, originally compiled by Primrose McConnell. 13th Edition.

Pedology Department

3.1. Bloomfield, C. (1957). The possible significance of polyphenols in soil formation. *J. Sci. Fd Agric.* **7**, 389.

The translocation of iron compounds down the profile of soils of the podzol group is considered to be caused by the action of soluble organic compounds leached from the overlying unhumified tree litter. The solution and reduction of ferric oxide is apparently caused by the joint action of carboxylic acids and polyphenols. As aqueous leaf extracts will disperse clay suspensions, it is apparent that the development of textural profiles could be promoted by the action of these extracts. In the dispersion of clays, polyphenolic compounds constitute one of the chief groups of active compounds.

3.2. Greene-Kelly, R. (1957). The montmorillonite minerals. In: *The Differential Thermal Investigation of Clays*, edited by R. C. Mackenzie; pp. 140–164. London: The Mineralogical Society.

3.3. Greene-Kelly, R. & Gallavan, R. C. (1957). A Microcalorimeter for clay mineral studies. *Clay Min. Bull.* **3**, 167–174.

The features required in a calorimeter for studying clay mineral systems are discussed, and a suitable calorimeter of high sensitivity is described in detail.

3.4. Greene-Kelly, R. & Weir, A. H. (1956). A silica spiral thermobalance for studies on the dehydration of clay minerals. *Clay Min. Bull.* **3**, 68–78.

Constructional details of the balance and methods to give maximum sensitivity in obtaining and presenting results are described. Examples of work on clay minerals include comparison of results from the balance with d.t.a. traces of kaolinite and halloysite, low-temperature dehydration of various montmorillonites and a series at different rates of heating showing the relation between the d.t.a. trace and the equilibrium isobaric dehydration curve of Li^+–Wyoming bentonite.

3.5. Muir, A. (1954). The soils of the Shire Valley. In: *A Report on the Control and Development of Lake Nyasa and the Shire River.* Vol. 2, pp. 129–178. London: Sir Wm. Halcrow and Partners.

An account of the distribution, morphology and properties of the soils in relation to geology, relief and agricultural potential.

3.6. Muir, A., Anderson, B. & Stephen, I. (1957). Characteristics of some Tanganyika soils. *J. Soil Sci.* **8**, 1–18.

A mineralogical study of soils, derived mainly from amphibolite, show that only small amounts of the more resistant aluminosilicate minerals survive. The clays of the red loams are characterized by a dominance of kaolinite, whereas the more poorly drained grey soils have a disordered kaolin (fire-clay mineral). Other components are iron oxides and small amounts of illite. The pallid soils contain moderate amounts of montmorillonite in the weathering zone, some of which persists into the soil. The mbuga and black valley soils contain montmorillonite or illite, with subordinate kaolin.

3.7. Muir, A. & Stephen, I. (1957). The superficial deposits of the Lower Shire Valley, Nyasaland. *Colon. geol. miner. Res.* **6**, 391–406.

Field observations on the physical features and superficial deposits, together with mineralogical examinations of the sand and clay fractions of the deposits, suggest that the bulk of the material forming the valley slopes is of a localized nature, and that its origin can be ascribed to a kind of pedisedimentation brought about in part by the various earth movements associated with the Rift Valley.

3.8. Osmond, D. A. & Stephen I. (1957). The micropedology of some red soils from Cyprus. *J. Soil Sci.* **8**, 19–26.

For abstract see below 16.3.

Soil Microbiology Department

Research Papers

4.1. Brown, Margaret E. & Metcalfe, G. (1957). Nitrogen fixation by a species of *Pullularia*. *Nature, Lond.* **180**, 282.

A species of *Pullularia* was isolated from clay-loam soil, chalk soil, heath soil and woodland mull soil and also from the thallus of the lichen *Cladonia uncialis*. Tests made with the fungus isolated from the clay-loam soil showed that the organism could fix 4–5 mg. of atmospheric nitrogen per g. of glucose supplied in the cultural medium. An estimation of the numbers of *Pullularia* in the soil gave an approximate count of 8×10^8 cells per g. of soil.

On nitrogen-rich media the fungus very rapidly loses its ability to fix atmospheric nitrogen.

4.2. Brown, Margaret E. (1958). Preliminary studies on the inoculation of partially sterilized soils with selected microorganisms. *J. gen. Microbiol.* **18**, 239–247.

For abstract see p. 80.

4.3. Jackson, R. M. (1957). Fungistasis as a factor in the rhizosphere phenomenon. *Nature, Lond.* **180**, 96–97.

The spores of certain fungi which are unable to germinate on glass slides buried in fresh soil, owing to the presence in the soil of a fungistatic factor, may do so readily when seedling roots grow in their immediate vicinity. This observation has been made with five fungi and three different plants.

Conidia of *Fusarium solani* and an unidentified species of *Fusarium* both normally produce chlamydospores in the soil and cease further development, but in the presence of seedling roots the chlamydospores germinate. With *Gliocladium roseum* and the *Fusaria* studied the germ tubes show a marked tropic growth towards the stimulating roots. *Paecilomyces marquandii*, although stimulated to germinate, shows no tropic response.

It is suggested that the rhizosphere effect is likely to be due as much to the indirect influence of root exudates in stimulating germination of inhibited fungal spores as to the subsequent direct nutritional effect of exudates and sloughed-off root tissue.

4.4. Jackson, R. M. (1958). An investigation of fungistasis in Nigerian soils. *J. gen. Microbiol.* **18**, 248–258.

The presence of a fungistatic factor in Nigerian soils was demonstrated by the use of a technique in which discs of agar are placed in contact with moist fresh soil and inoculated with fungal spores. After incubation the discs are examined and the percentage of germinated spores recorded.

Inhibition of germination was not caused by autoclaved soil nor when 0·5 per cent (w/v) glucose is present in the agar. The presence or absence and the type of vegetation had little effect on the fungistatic power of the soil. In two profiles examined the property of fungistasis was confined to approximately the upper 40 cm. of the soil. Of nineteen species of fungi tested by the agar-disc method, the germination of eleven was significantly inhibited, of seven unaffected and of one stimulated.

The data obtained suggest that the phenomenon described in Nigerian soils is similar to that reported from other parts of the world.

4.5. (Metcalfe, G.) & Brown, Margaret E. (1957). Nitrogen fixation by a new species of *Nocardia*. *J. gen. Microbiol.* **17**, 567–572.

Two new species of the genus *Nocardia* (Trev.) have been isolated from the soil of chalk grassland. One of these, *Nocardia calcarea* n.sp., fixes atmospheric nitrogen in culture in amounts of 2–4·5 mg. N g. glucose, sucrose or mannitol present in the medium. The second species, *N. cellulans* n.sp., decomposes cellulose in culture and fixes atmospheric nitrogen in culture using glucose, sucrose, mannitol and cellulose as carbon source; amounts of 12 mg. N fixed g. cellulose decomposed were recorded. The properties of nitrogen fixation and cellulose decomposition have not previously been recorded for this genus.

4.6. Walker, N. (1957). The persistence in soil of bacteria adapted to the decomposition of hormone herbicides. *Turf for Sport*, **3**, No. 2.

After repeated sprayings of turf with commercial preparations of either 2 : 4-D or MCPA, the soil micro-flora became adapted to decompose these herbicides. It was shown that these adapted organisms persisted in the soil for 12 months after the sprayings were discontinued.

Review Articles

4.7. Meiklejohn, Jane (1957). Nitrification in soil. *N.A.A.S. Quart. Rev.* (In the press.)

4.8. Thornton, H. G. & Meiklejohn, Jane (1957). Soil Microbiology. *Ann. Rev. Microbiol.* **11**, 125–148.

Book

4.9. *Magnesium, the fifth major plant nutrient.* By A. Jacob. English translation by N. Walker. London: Staples Press Ltd., 1957.

Botany Department

General Papers

5.1. Watson, D. J. (1957). The physiological basis of the effect of potassium on crop yield. In: *Potassium Symposium 1956*. Bern: International Potash Institute, pp. 109–119.

5.2. Humphries, E. C. (1958). Effect of removal of a part of the root system on the subsequent growth of the root and the shoot. *Ann. Bot. Lond.*, N.S. (In the press.)

Removal of up to 50 per cent of the roots of barley or rye had no effect on the growth rate of the root, but the growth rate of the shoot decreased as more roots were removed. When more than 50 per cent of the roots were removed, root growth declined, but not so rapidly as that of the shoot. Removal of lateral roots of tomato gave similar results, but root growth began to decline when more than 40 per cent of the lateral roots were removed.

5.3. Owen, P. C. (1957). The effect of ultra-violet radiation on the respiration rate of tobacco leaves, and its reversal by visible light. *Nature, Lond.* **180**, 610.

The respiration rate of tobacco leaves exposed to radiation of wavelength 2,537 Å. for 5 minutes was increased by 20 per cent, but if the leaves were exposed to natural visible light for 2 hours after irradiation this effect disappeared.

5.4. Owen, P. C. (1957). Rapid estimation of the areas of the leaves of crop plants. *Nature, Lond.* **180**, 610–611.

A method of leaf-area measurement described by other workers has been modified for use with leaves whose shapes are not regular ellipses.

5.5. Owen, P. C. (1957). The effects of infection with tobacco mosaic virus on the photosynthesis of tobacco leaves. *Ann. appl. Biol.* **45**, 456–461.

The rate of photosynthesis of tobacco leaves infected with tobacco mosaic virus was lower than that of comparable healthy leaves from within 1 hour of inoculation. It was not caused by an effect of the virus on the stomata, and inactivated virus did not affect the rates. These results indicate either a more rapid movement of virus from the epidermis into the chlorenchyma than has previously been recorded or an effect of virus infection at a site distant from the cells containing virus.

5.6. Owen, P. C. (1958). Photosynthesis and respiration rates of leaves of *Nicotiana glutinosa* infected with tobacco mosaic virus and of *Nicotiana tabacum* infected with potato virus X. *Ann. appl. Biol.* (In the press.)

The rates of respiration and of photosynthesis of tobacco leaves infected with potato virus X were not affected until the leaves showed symptoms; the respiration rate was then increased by more than 30 per cent, and the photosynthesis rate decreased by 20 per cent. When local lesions appeared on the leaves of *N. glutinosa* infected with tobacco mosaic virus, but not before, the respiration rate was increased by an amount, up to 30 per cent, that varied with the number of lesions. The photosynthesis rate was decreased by 20 per cent, but there was no effect on either respiration or photosynthesis until symptoms appeared. These results differed from those previously reported for tobacco leaves infected with tobacco mosaic virus, in which both respiration and photosynthesis were affected within 1 hour of inoculation. The validity of extrapolating arguments based on the results obtained with other combinations to this commonly used combination and vice-versa is questioned.

5.7. Owen, P. C. (1958). Some effects of virus infection on leaf water contents of *Nicotiana* species. *Ann. appl. Biol.* (In the press.)

Infection with tobacco mosaic virus decreases the water content attained by detached tobacco leaves when kept under conditions of minimum water stress, and does so more with plants kept in light than in darkness before inoculation. No such effects of infection during the first day after inoculation were obtained with tobacco leaves infected with either tobacco etch virus or potato virus X or with *Nicotiana glutinosa* leaves infected with tobacco mosaic

virus. These results suggest that inoculation with tobacco mosaic virus affects tissues deeper than the epidermis in tobacco leaves earlier than in other leaves, and earlier than other viruses affect tobacco leaves.

5.8. THORNE, G. N. (1957). The effect of applying a nutrient in leaf sprays on the absorption of the same nutrient by the roots. *J. exp. Bot.* **8**, 401–412.

Ammonium nitrate solution applied to the leaves of sugar beet increased plant dry weight and uptake of nitrogen by the roots. Uptake of phosphorus by the roots of swedes, but not sugar beet, grown with high phosphorus supply to the roots, was decreased by applying sodium phosphate solution to the leaves; uptake from a lower phosphorus supply to the roots was unaffected. Phosphorus applied to the leaves had no effect on dry weight. Potassium uptake by the roots of sugar-beet plants grown with high potassium supply to the roots was unaffected by painting the leaves with a potassium chloride solution, that of plants with an intermediate potassium supply was slightly increased, and plants grown with a low supply to the roots absorbed almost all the available potassium, so painting could not much increase uptake by the roots. Application of potassium to the leaves increased dry weight of plants with low or medium potassium supply to the roots and did not affect that of plants with a high potassium supply.

The top : root ratio for phosphorus content in mg. per plant was greater for phosphorus absorbed via leaves than for phosphorus absorbed via roots. Increasing the phosphorus supply to the roots increased this ratio for phosphorus absorbed either via leaves or roots.

Potassium absorbed by leaves was slightly more efficient in increasing dry weight than potassium absorbed at the same time by the root. A similar comparison was not possible for nitrogen or phosphorus.

The results of these and previous experiments indicate that all the nitrogen and potassium and over 80 per cent of the phosphorus applied to leaves was absorbed. The small amount of phosphorus remaining unabsorbed on the surface of the leaf was unaffected by phosphorus supply to the root.

5.9. THURSTON, J. M. (1957). Morphological and physiological variation in wild oats (*Avena fatua* L. and *A. ludoviciana* Dur.) and in hybrids between wild and cultivated oats. *J. agric. Sci.* **49**, 259–274.

In samples of wild oat panicles collected in England and Wales in 1951 only two species, *Avena fatua* L. and *Avena ludoviciana* Dur., occurred; both were very variable in grain characters, but most plants bred true. Plants of all except one type of *A. fatua* were upright in habit with few tillers and averaged 95 per cent dormant grains at harvest; plants of *A. ludoviciana* were procumbent or prostrate at the maximum tillering stage with numerous tillers, and the percentage of dormant grains was lower than in *A. fatua*.

The taxonomy of wild oats is discussed. Chromosome counts on eleven selections showed that $2n = 42$.

Types intermediate between wild and cultivated oats were compared with wild oats.

5.10. WARINGTON, K. (1957). The influence of the pH of the nutrient solution and the form of iron supply on the counteraction of iron deficiency in peas, soybean and flax by high concentrations of molybdenum. *Ann. appl. Biol.* **45**, 428–447.

The prevention of chlorosis in flax by high concentrations of molybdenum in a nutrient solution was associated with a delay in the precipitation of iron from ferric citrate, a slower drift of pH towards alkalinity and an increase in the iron content of the root. These effects were greater with ammonium than with sodium molybdate, and occurred with solutions started at pH 4·6 but not at pH 6·6.

When FeEDTA was the source of iron, a similar delay in pH drift in the solution and accumulation of iron in the root occurred, but there was no chlorosis or precipitation of iron in the control treatment, so the effect of high molybdenum could not be fully determined.

When ferric chloride was used, high molybdenum did not prevent chlorosis nor delay iron precipitation or cause accumulation of iron in the root, though the rate of pH drift resembled that of solutions containing the organic forms of iron.

Similar results were obtained with peas and soybeans receiving high molybdenum treatment, but suppression of chlorosis was only temporary.

It is suggested that the capacity of molybdenum to offset chlorosis is due to the formation, in acid solution, of a complex with phosphorus which renders iron more available by delaying the formation of ferric phosphate. This seems to occur only when iron is supplied in the organic form.

5.11. WARINGTON, K. (1958). Changes in the weed flora on Broadbalk Permanent Wheat Field during the period 1930–55. *J. Ecol.* **46**, 101–113.

The reduction in annual species achieved by the intensive fallow of 1926–29 has on the whole been maintained, that of *Papaver rhoeas* being the outstanding example, though since 1953 there have been signs of the return of this weed. *Alopecurus myosuroides*, another principal weed, on the other hand, has only been temporarily checked by the once-in-5-year fallow and has quickly re-established itself, though less noticeably so since 1953. Other species have become much more plentiful, e.g., *Ranunculus arvensis*, *Vicia sativa* and *Avena* spp., though the last has now been gradually eliminated by hand-pulling.

Germination results from soil samples agree remarkably well with field rating records, but comparison is limited to the species prevalent on the plots selected for sampling. Unfortunately no germination data are available for the period 1946–54 when considerable changes in weed flora took place.

Perennials were unimportant in 1930. Of the species then present *Sonchus arvensis* has failed to return, but *Cirsium arvense* has once more become a serious weed, chiefly since 1943. *Convolvulus arvensis* is also re-established, but *Tussilago farfara* and *Equisetum* remain relatively unimportant and of local occurrence only.

5.12. WATSON, D. J. (1958). The dependence of net assimilation rate on leaf area index. *Ann. Bot. Lond.*, N.S. **22**, 37–54.

The leaf-area index (leaf area per unit area of land, L) of field crops of kale and sugar beet was varied experimentally by removing different fractions of the plant population distributed uniformly through the crop. The net assimilation rate (E) was determined in subsequent periods of 10–14 days.

For kale, E decreased nearly linearly with increase in L throughout the range from 1 to 5. E for sugar beet was less affected by change in L, and was apparently not decreased until L rose above about 3.

Because of this dependence of E on L, the rate of dry-matter production per unit area of land, or crop growth rate (C, $= EL$), showed a curved relation to L; for kale it increased to a maximum when L was between 3 and 4 and fell again at higher values of L. Maximal C for sugar beet occurred beyond the range of L tested, probably between $L = 6$ and $L = 9$. This optimal L for dry-matter production by sugar-beet crops probably lies near the upper limit of the current agricultural range, so there is little, if any, scope for increasing the dry-matter yield by further increase in L. For heavy kale crops L is already far in excess of the optimum, and it may be possible to increase the total dry-matter yield of kale by repeated thinning or defoliation to hold L near the optimum.

5.13. WATSON, D. J., THORNE, G. N. & FRENCH, S. A. W. (1958). Physiological causes of differences in grain yield between varieties of barley. *Ann. Bot. Lond.*, N.S. (In the press.)

In a field experiment on barley at Rothamsted with the high mean yield of 49 cwt. of grain/acre, the varieties Proctor and Herta produced 10–15 per cent more grain than Plumage Archer on plots that received no nitrogenous fertilizer. When nitrogen was applied the difference was increased to about 30 per cent, because the higher nitrogen supply caused the Plumage Archer crop to lodge and did not increase its yield, while Proctor and Herta remained standing.

The three varieties did not differ in leaf-area index nor in net assimilation rate before ear emergence, so that all had the same total dry weight. After ear emergence, the leaf-area indices of Proctor and Plumage Archer were nearly equal, but that of Herta was smaller. Assuming that the photosynthetic efficiency of the leaves continued to be the same in all varieties, the higher grain yields of Proctor and Herta cannot be attributed to greater production of dry matter by the leaves, either before or after ear emergence.

The higher grain yield of Proctor and Herta than of Plumage Archer must therefore have come from additional photosynthesis in parts of the plant other than the leaves, i.e., in the ears themselves. An attempt to demonstrate this directly in a pot experiment by comparing the grain yields of plants with shaded or with unshaded ears was unsuccessful because the varieties behaved differently in pots; Proctor and Herta produced only about 6 per cent more grain yield than Plumage Archer, and though the decrease in grain yield by shading the ears was slightly greater for Proctor and Herta, the differences were not significant.

The sum of ear sizes per m.^{2} in the field experiment was greater for Proctor and Herta than for Plumage Archer. Also the distribution of dry matter between developing ears and shoots apparently differed with variety, so that at ear emergence the dry weight of ears per m.^{2} was greater in the two higher-yielding varieties. The increased amount of photosynthetic tissue in the ears of Proctor and Herta, as measured by size or weight, may not wholly explain their greater dry-matter production; ears of Herta may also have a higher photosynthetic efficiency.

No differences in nutrient uptake that could account for the varietal differences in grain yield were found. Plumage Archer absorbed more potassium and Herta less phosphorus than the other varieties.

Biochemistry Department

Books

6.1. Tracey, M. V. (1956). *Modern Methods of Plant Analysis.* Edited by K. Paech & M. V. Tracey. Vol. 1. Berlin: Springer Verlag.

General Papers

6.2. Pirie, N. W. (1957). The Origins of Life: Moscow Symposium. *Nature, Lond.* **180**, 886–888.

6.3. Pirie, N. W. (1957). Some assumptions underlying discussion on the Origins of Life. *Ann. N.Y. Acad. Sci.* **69**, 369–376.

6.4. (Le Gros Clark, F.) & Pirie, N. W. (1957). Introduction to the symposium on " The Biology of Ageing," edited by W. P. Yapp & G. H. Bourne. Institute of Biology, x–xvi.

6.5. Pirie, N. W. (1958). Unconventional production of foodstuffs. " The Biological Productivity of Britain ", Institute of Biology.

6.6. Pirie, N. W. (1958). The unconventional production of foodstuffs. *Penguin Sci. News.*

6.7. Tracey, M. V. (1957). Chitin. *Rev. pure & appl. Chem.* **7**, 1–14.

6.8. Tracey, M. V. (1957). The role of cellulases in nature. Friday Harbor Symposium in Marine Biology. (In the press.)

6.9. Kenten, R. H. (1957). The partial purification and properties of a thiaminase from bracken (*Pteridium aquilinum* (L.) Kühn). *Biochem. J.* **67**, 25–33.

A method for the estimation of small amounts of heteropyrithiamine (*N*-(4-amino-2-methylpyrimidin-5-yl)methylpyridine) in the presence of thiamine is described. It depends on the destruction of thiamine by incubation with strong alkali and subsequent oxidation of heteropyrithiamine to 2-methylpyrichromine by ferricyanide. The 2-methylpyrichromine is estimated spectrophotometrically at 386 mμ.

With the method it is shown that bracken thiaminase catalyses a transfer reaction between thiamine and pyridine with the formation of heteropyrithiamine. In the presence of excess of pyridine the amount of heteropyrithiamine formed accounts for 90–95 per cent of the thiamine added.

A relatively simple method for the measurement of bracken-thiaminase activity is described.

By fractionation with ammonium sulphate and calcium phosphate gel, concentrated partially purified thiaminase preparations have been made from water extracts of dried bracken leaves. The best preparation was obtained in 30 per cent yield and represented a purification of about 60-fold. It catalysed the formation of 3,150 μmoles of heteropyrithiamine/hour/mg. of N at 37°.

With the concentrated partially purified preparations, no evidence was obtained for the presence of a thermolabile factor capable of catalysing the hydrolytic fission of thiamine.

6.10. Kenten, R. H. (1957). Latent phenolase in extracts of broad bean (*Vicia faba* L.) leaves. 1. Activation by acid and alkali. *Biochem. J.* **67**, 300–307.

Water extracts of broad-bean leaves contain much latent phenolase activity.

Active phenolase is released by brief exposure of the extracts to acid (pH 3–3·5) or alkaline (pOH 2·5–3) conditions or by incubating in the presence of ammonium sulphate at about pH 5.

Evidence has been obtained that the extracts contain little material capable of inhibiting broad bean phenolase.

The nature of the latent phenolase has not been elucidated, but it is suggested that either a phenolase precursor or a phenolase-protein inhibitor complex is present in the leaf extracts.

6.11. Kenten, R. H. (1957). Latent phenolase in extracts of broad bean (*Vicia faba* L.) leaves. 2. Activation by anionic wetting agents. *Biochem. J.* **68**, 244–251.

The latent phenolase of extracts of broad-bean leaf is activated with anionic wetting agents at pH 6. A number of cationic and non-ionic wetting agents were without effect.

With the homologous series of sodium *n*-alkyl sulphates tested the concentration at which activation of the latent phenolase took place decreased with increase in chain length.

At pH 8 the rate of activation with sodium dodecyl sulphate and Aerosol OT was very slow or negligible compared with that at pH 6.

It is suggested that the anionic wetting agents activate through their capacity to combine with the cationic groups of protein. Dissociation of a phenolase-protein inhibitor complex or configurational changes in a prophenolase might follow such combination.

6.12. Pierpoint, W. S. (1957). The phosphoesterase of pea plants (*Pisum sativum* L.). *Biochem. J.* **67**, 466–472.

A purified preparation of a phosphatase from peas breaks the phosphomonoester bonds in a wide range of compounds. Pyrophosphate is an intermediate in the breakdown of tripolyphosphate to orthophosphate. The enzyme also breaks the diester bonds in trimetaphosphate, although not those in nucleic acids or diphenyl phosphate. The di- and mono-esterase activities

are not separated by a variety of protein fractionation procedures, including paper electrophoresis and ion-exchange chromatography. The chromatography resolves the phosphatase into two active components. This heterogeneity is not caused by the ammonium sulphate precipitation in the preparation of the enzyme.

6.13. Pierpoint, W. S. (1957). Polyphosphates excreted by the wax-moth larvae (*Galleria mellonella* L. and *Achroia grisella* Fabr.). *Biochem. J.* **67**, 624–627.

The excreta of wax-moth larvae feeding on brood comb contains about 0·5–1·0 per cent of its dry weight as phosphorus. About half of this phosphorus is water soluble and hydrolysed to orthophosphate by boiling with normal hydrochloric acid for 10 minutes. The water-soluble phosphates excreted by *G. mellonella* were analysed by anion-exchange chromatography, and shown to consist of orthophosphate 14 per cent, pyrophosphate 23 per cent, tripolyphosphate 44 per cent, acid-stable phosphate 3 per cent and a fraction retained by the resin, probably polyphosphates of higher molecular weights, 16 per cent. Water-soluble phosphates were excreted by *A. grisella* larvae in similar proportions, but with slightly more orthophosphate (29 per cent) and less of the material retained by the resin (6 per cent).

6.14. Pirie, N. W. (1957). Leaf protein as a human food. *Food Manufacture*, **32**, 416–419.

A brief account of the performance of the extraction machinery, of the methods used in getting an easily handled final product and of the trials that have been made of different techniques of cookery.

6.15. Bawden, F. C. & Pirie, N. W. (1957). A virus inactivating system from tobacco leaves. *J. gen. Microbiol.* **16**, 696–710.

For summary see below No. 7.9.

6.16. Bawden, F. C. & Pirie, N. W. (1957). The activity of fragmented and reassembled tobacco mosaic virus. *J. gen. Microbiol.* **17**, 80–95.

For summary see below No. 7.10.

6.17. Tracey, M. V. & (Youatt, G.) (1957). Cellulase and chitinase in two species of Australian termites. *Enzymologia*. (In the press.)

Extracts from both *Nasutitermes exitiosus* and *Coptotermes lacteus* contain cellulase and chitinase activity. The significance of these findings is discussed.

6.18. Tracey, M. V. (1957). Cellulase and chitinase in plant nematodes. *Nematologica*. (In the press.)

Cellulase and chitinase were found in extracts of *Ditylenchus dipsaci*, *D. destructor* and *D. mycetophagus*. It appears probable that these enzymes are a product of the nematodes themselves and not of associated micro-organisms. Some figures for the gross composition of the eelworms are given.

Plant Pathology Department

General Papers

7.1. Bawden, F. C. (1957). Tobacco mosaic virus. (In: *Cellular biology nucleic acids and viruses*, New York Academy of Sciences.)

7.2. Bawden, F. C. (1958). The nature of plant viruses. *Outlook on Agric.* (In the press.)

7.3. Bawden, F. C. (1957). The role of plant hosts in microbial ecology. (In: *Symp. Soc. gen. Microbiol.* **7**: *Microbial Ecology*.)

7.4. Broadbent, L. (1957). Insecticidal control of the spread of plant viruses. *Ann. Rev. Entom.* **2**, 339–354.

7.5. Broadbent, L. (1958). The spread and control of plant viruses. *Sci. Hort.* **13**.

7.6. Buxton, E. W. (1957). Problems of plant wilt diseases. *Agric. Rev.* **3** (7), 28–35.

7.7. Hull, R. (1957). Sugar Beet Yellows in Great Britain, 1956. *Plant Path.* **6**, 131.

Research Papers

7.8. Bawden, F. C. & Kleczkowski, A. (1957). An electrophoretic study of sap from uninfected and virus-infected tobacco plants. *Virology*, **4**, 26–40.

The number and concentration of electrophoretically distinguishable components in sap from uninfected tobacco leaves varied with the position of the leaf on the stem, the age of the plants, their nutrition and conditions of growth. None of the distinguishable proteins seemed to be homogeneous. Sap from the lowest leaves contained something that aggregated the proteins and produced unstable electrophoretic patterns; stable patterns were obtainable when the proteins were precipitated with ammonium sulphate and redissolved.

Infection with tobacco mosaic virus or potato virus X, but not with tobacco etch or potato Y virus, introduced new components into the electrophoretic pattern. Unlike tobacco mosaic virus, potato virus X was stationary in pH 7 phosphate buffer; two minor components specific to sap from leaves infected with potato virus X had mobilities of -2 and -4×10^{-5} cm.^{2}sec.$^{-1}$v^{-1}.

The concentration of normal proteins was not correlated with severity of leaf symptoms, and was not consistently affected by virus infection. Potato Y and tobacco etch viruses usually did not affect the concentration, but sometimes decreased it slightly. Potato virus X and tobacco mosaic virus sometimes considerably decreased the concentration of normal proteins, usually when young rapidly growing plants were used and the conditions favoured a high virus content, but even in these conditions the amount of normal proteins was sometimes unaffected. Simultaneous infection with potato X and tobacco mosaic viruses, each of which accumulated to the same extent as when present alone, had no more effect on the normal proteins than did infection with one or the other alone.

7.9. Bawden, F. C. & Pirie, N. W. (1957). A virus-inactivating system from tobacco leaves. *J. gen. Microbiol.* **16**, 696–710.

Purified preparations of the Rothamsted tobacco necrosis virus made by sedimenting the virus from freshly expressed sap lose infectivity slowly at 0° and rapidly at 18°. Stable infective preparations can be made by ultracentrifugation provided the sap is first frozen or allowed to age; unstable preparations can be stabilized by prolonged centrifugation at 8,000*g*, or by incubation with citrate and azide. Stable virus preparations lose their infectivity when exposed to the material that sediments from leaf sap centrifuged at 4,000–8,000*g*. This inactivation demands air, and is prevented by the presence of azide, but when the sedimented material is kept in air at 0° for some hours a low-molecular-weight substance separates from it, and this inactivates the virus whether or not air or azide are present. The material sedimented from the sap of uninfected tobacco leaves, or leaves infected with tobacco mosaic virus, inactivates virus less readily than does material from leaves infected with tobacco necrosis or tobacco ringspot virus. The sediments inactivate tobacco ringspot but not tobacco mosaic virus. The nature of the inactivating substance made by the sediments is unknown, but aldehydes and derivatives of ascorbic acid have comparable effects. Inactivated virus preparations are still serologically active and resemble active ones in all other properties studied.

7.10. Bawden, F. C. & Pirie, N. W. (1957). The activity of fragmented and reassembled tobacco mosaic virus. *J. gen. Microbiol.* **17**, 80–95.

Studies of the products obtained when tobacco mosaic virus (TMV) is disrupted with alkali or phenol suggest that immunological specificity is primarily an attribute of the protein and infectivity of the nucleic acid. Although exposing the virus to alkali produces infective fragments, it also causes much inactivation, and much of the nucleoprotein sedimented when preparations are ultracentrifuged at pH 6 is not infective. The unsedimented protein fragments are inhibitors of infection; from such unsedimentable material which at 5 g./l. produced no lesions when inoculated to *Nicotiana glutinosa*, some infective nucleoprotein could sometimes be separated by precipitation with ammonium sulphate, followed by ultracentrifugation. The infectivity of fragmented TMV is ephemeral, but it is stabilized when the fragments are reunited. Nucleic acid preparations made by phenol are quickly inactivated by ribonucleases from pancreas or leaves; pancreatic ribonuclease also inactivates alkali-made fragments, but the infectivity of these is stabilized by leaf ribonuclease. Phenol-made preparations are much less infective per unit of phosphorus than intact TMV, but measurements of the relative infectivities of the two kinds of inocula are complicated because the two respond differently to dilution and they are not equally able to infect *N. glutinosa* leaves in different physiological states. Although urea does not inactivate phenol-made preparations, nucleic acid made by exposing TMV to urea has little or no infectivity. The possibility that infective TMV can be reassembled *in vitro* from previously non-infective components cannot be excluded, but all the results that could be interpreted as suggesting this are also interpretable in other ways, either by the removal of inhibitors of infection or by the stabilization of infective fragments that otherwise would have become inactive before testing.

7.11. Broadbent, L., Burt, P. E. & (Nix, J. S.) (1957). The cost of using insecticides to maintain the health of potato seed in England and Wales. *N.A.A.S. Quart. Rev.*, **38**.

The useful life of potato seed stocks in the south and east of Britain can be prolonged by spraying with insecticides which check the spread of aphid-borne viruses, especially of leaf roll from infected to healthy plants within a crop. Spraying, combined with removing the plants that become infected by aphids bringing viruses into healthy stocks, costs £8 to £11/acre less per year than buying new "A" or Stock Seed, but the saving depends on the method adopted and current market prices. The cheapest method is to spray and rogue a ware crop and save seed from this, but there may sometimes be advantages to offset the slightly greater cost of growing a crop specially for seed.

7.12. Broadbent, L., (Green, D. E. & Paton, J. B.) (1957). Virus diseases in the Narcissus Trial at Wisley. *J. R. hort. Soc.* **82**, 395–401.

The Narcissus stocks were freed from severe virus diseases by roguing obviously diseased plants and by planting the plots between barriers of rye, but each year new stocks sent for trial by British and Dutch growers contained diseased plants. Many infected plants showed symptoms in some years, but not in others.

7.13. Broadbent, L., Heathcote, G. D., (McDermott, N. & Taylor, C. E.) (1957). The effect of date of planting and of harvesting potatoes on virus infection and on yield. *Ann. appl. Biol.* **45**, 603–622.

Experiments during 1953–56 tested the effects of early and late planting of King Edward potatoes on the incidence of virus diseases in the tubers and the suitability of the tubers for use as seed. Plantings were made each month from April to August, and tubers were lifted after 12 weeks' growth or after the haulms had died.

Aphids began to colonize the early planted plots about mid-June each year, but their multiplication and flying were influenced by weather and varied greatly from year to year. The May-planted plots usually carried the most aphids. Winged aphids visited the July and August plantings, but few bred extensively though the plants were young and green. The incidence of virus diseases in the tubers was not related to the maximum aphid populations on the plants. Most of the plants that became infected became so by aphids flying from diseased potato plants in the same field, and the late-planted plots did not escape. Crops planted in mid-April and harvested in early July produced the fewest virus-infected tubers.

Planting in April and lifting at the end of the season produced most ware-sized tubers. In plots lifted after 12 weeks, May or June planting produced more ware than April planting. Few or no ware-sized tubers were produced from July or August planting, and yields of seed-sized tubers were also poor. Most seed-sized tubers were produced by the late-lifted May or June plantings. The date of lifting had little effect on the total number of tubers, but the date of planting affected it greatly. Most tubers were usually set by the May plantings, and the number decreased with successive plantings. Early lifted immature tubers were easily damaged and were difficult to store. Blighted tubers occurred only in the July or August plantings, which also suffered most from slug and cutworm damage.

Infection with leaf roll virus reduced yield by about three-quarters, whether the seed had been lifted early or late the previous year. Healthy or virus-infected mature seed produced a bigger crop the next year than immature seed obtained by early lifting or late planting.

Late-planted tubers produced more main stems than those planted at the normal time, but growth of axillary shoots was reduced and total leaf area remained small, even when the plants were not attacked by blight.

7.14. Broadbent, L., Heathcote, G. D. & (Mason, E. C.) (1958). An Essex farm trial on the insecticidal control of potato virus spread. *Plant Path.* **7**.

A stock of originally healthy King Edward potatoes sprayed each year for 4 years, three times at monthly intervals, with the systemic insecticides dimefox or demeton, or six times at fortnightly intervals with parathion, contained in the fourth year 0·5 per cent of plants with leaf roll, whereas an unsprayed stock contained 26 per cent. The insecticides failed to prevent the spread of virus Y; the incidence of infected plants in the fourth year was 19 per cent in the parathion-sprayed stock, 31 per cent in those treated with systemic insecticides and 35 per cent in the untreated.

7.15. Buxton, E. W. (1957). Differential rhizosphere effects of three pea cultivars on physiologic races of *Fusarium oxysporum* f. *pisi*. *Trans. Brit. mycol. Soc.* **40**, 305–317.

Pea cultivars Onward, Alaska and Delwiche Commando, differential hosts for three physiologic races of *Fusarium oxysporum* f. *pisi* (cause of pea wilt), exert different effects on the soil microflora. Cultivar Onward, susceptible to race 1, supports more fungi, bacteria and Actinomycetes near its root surface than do either Alaska or Delwiche Commando, which resist race 1. Qualitative differences between rhizosphere populations of the three cultivars are most apparent in *Fusaria* and bacteria.

The germination of spores of the three physiologic races of *F. oxysporum* f. *pisi* was affected by water extracts of the three rhizosphere soils in the same way as earlier with root exudates from the three cultivars. Spores of a race able to wilt a particular cultivar germinate well in rhizosphere soil extract from that cultivar. Germination is decreased, on the other hand, in extracts from the rhizosphere of a resistant cultivar. Spores of race 3, however, were not able to germinate well in rhizosphere extract of cultivar Alaska, which is susceptible to this race.

Soils in which each of the three pea cultivars had grown were inoculated with spores of race 1 and planted with seedlings of the susceptible cultivar Onward. Plants became severely wilted in pots in which Onward had grown and in control pots which had not grown peas, but wilting was less and developed more slowly in pots which had previously been cropped with cultivars Alaska and Delwiche Commando (which resist race 1). It is suggested that substances

exuded by roots of cultivars resistant to race 1, together with the effect of altering the soil microflora, prevent race 1 from germinating, thus lowering the amount of effective inoculum and delaying the onset of wilt.

7.16. Buxton, E. W., Last, F. T. & Nour, M. A. (1957). Some effects of ultraviolet radiation on the pathogenicity of *Botrytis fabae*, *Uromyces fabae* and *Erysiphe graminis*. *J. gen. Microbiol.* **16**, 764–773.

Ultra-violet irradiation of spores of three leaf-infecting fungi, *Botrytis fabae*, *Uromyces fabae* (causes of " chocolate spot " and rust of broad beans, respectively) and *Erysiphe graminis* (cause of barley powdery mildew), decreased their pathogenicity, as assessed by counts of local lesions or pustules. The infectivity of *B. fabae* was lost more rapidly than the ability to form colonies on agar; with *E. graminis* infectivity was lost more rapidly than the ability to germinate. Ultra-violet radiation damage to spores of all three fungi was mitigated by exposure to daylight after irradiation. The extent of such photoreactivation of *B. fabae* was the same whether the spores were on the host plant or *in vitro*. Ultra-violet irradiation of leaves before inoculation decreased the number of pustules of *E. graminis* on barley, had no effect on the pustule number caused by *U. fabae* and increased the number of lesions caused by *B. fabae* on broad beans. Rubbing leaves with " Celite " before inoculation also increased the number of *B. fabae* lesions. Retaining irradiated broad-bean plants in daylight or darkness after inoculation with unirradiated spores of *B. fabae* did not significantly alter the lesion number. In contrast, more pustules of *E. graminis* developed on irradiated barley leaves kept in daylight than in darkness.

7.17. Cornford, C. E. & Powell, D. B. (1957). Effect of gamma rays on the sprouting of stored mangolds. *Nature, Lond.* **180**, 996.

Gamma rays prevented stored mangolds from sprouting.

7.18. Glynne, M. D. & Slope, D. B. (1957). The effect of seed rate and nitrogen on lodging and yield of spring barley (Field experiments 1954 and 1955). *J. agric. Sci.* **49**, 454–458.

The extent to which spring barley crops lodged at Rothamsted increased with seed rate and with nitrogen, and was larger in the wet summer of 1954 than the dry one of 1955. Although in 1954 all plots were extensively lodged by harvest, there were great differences in date of lodging; 50 per cent of the area was lodged later in plots sown with 1 than with 3 bushels/acre, the delay being 8 days with 1½ cwt. sulphate of ammonia, 14 days with 3 cwt. and 21 days with 4½ cwt. The weight of unit length of the basal part of the straw was reduced by higher seed rate and to a smaller extent by nitrogen.

Yield of total grain was only slightly affected by treatments; yield of dressed grain was decreased by higher seed rate in one year and by nitrogen in both years.

7.19. Gregory, P. H. & Hirst, J. M. (1957). The summer air-spora at Rothamsted in 1952. *J. gen. Microbiol.* **17**, 135–152.

The air over an arable field at Rothamsted Experimental Station, Harpenden, was sampled from 1 June to 25 October 1952 at 2 m. above ground with an automatic volumetric spore trap. Each day's slide was scanned and all the spores counted on an area representing a sample volume of 41 litres of air. Spores were classified in twenty morphological groups and a miscellaneous one. Seasonal periodicities are presented as 6-day running means of the daily average number of spores/m.^{3} air, and then related to meteorological data. *Cladosporium* conidia accounted for 46 per cent of the total catch; hyaline basidiospores (chiefly *Sporobolomyces*) for 31 per cent; and pollen only 1 per cent. The relative frequency of various spore types differs from that recorded by earlier workers because the suction trap catches spores of all sizes with almost equal efficiency and is little influenced by external conditions. The results, which should be representative of large rural areas of central and south England, show that the major changes of spore concentration depend on the weather and the phenology of the local vegetation and its associated fungal

flora. During 24 days in late June and July comparable estimates of spore concentration were made with another trap 24 m. above ground. The spore concentration of the twelve commonest groups at 24 m. totalled 82 per cent of that at 2 m.

7.20. Heathcote, G. D. (1957). The comparison of yellow cylindrical, flat and water traps, and of Johnson suction traps, for sampling aphids. *Ann. appl. Biol.* **45**, 133–139.

Different traps were compared to find the type most suitable for studying aphid vectors of plant viruses quantitatively.

A Moericke water trap caught more aphids than a flat sticky trap of equal area. A flat sticky trap (930 sq. cm.) caught half as many aphids as a cylindrical trap (945 sq. cm.), which caught about one-third as many as a water trap (1,200 sq. cm.), or a Johnson suction trap (9-inch fan) when operated at between 2 and 3 feet over bare soil.

Yellow traps caught proportionally more *Tuberculoides annulatus*, and in summer more *Capitophorus* species than a suction trap, but significantly fewer *Anoecia corni*, *Sitobium* spp. and *Pemphigus bursarius*. Traps with a level surface caught proportionally more *Brevicoryne brassicae*, *Aphis fabae* and *Myzus persicae*, but fewer *Anoecia corni* and *Drepanosiphum plantanoides* than vertical cylindrical traps. Attraction by colour influences the catch on horizontal traps more than on cylindrical traps because there is less impaction by the wind.

Only suction traps indicate the number of aphids per unit volume of air and are non-selective, but they are expensive and require an electric power supply. Water traps effectively catch those aphids that are attracted to yellow, but they require frequent attention. Sticky traps catch fewer aphids than either suction or water traps, but they can be left unattended for about 2 weeks. Flat, sticky traps catch aphids likely to land on a crop, and cylindrical traps show when aphids are in the air, but not if those aphids are able or wanting to land. For routine work cylindrical sticky traps have other advantages; they are cheap and do not require skilled handling, and their catches of alate *Myzus persicae* have been correlated with the spread of some plant viruses.

7.21. Heathcote, G. D. (1957). The optimum size of sticky aphid traps. *Plant Path.* **6**, 104–107.

Cylindrical sticky traps 12 cm. wide usually caught more aphids than traps 6 cm. wide, which caught more than traps 3 cm. wide, but doubling the surface area did not double the catch. In windy weather a greater proportion of aphids are swept past a wide cylinder in the divided air stream than past a narrow one, so that narrow traps catch more per unit area than wide ones.

Yellow traps caught more aphids per unit area than black ones. Square horizontal traps, 225, 900 and 3,600 sq. cm. in area, caught increasing numbers of aphids with increase in size; the catch per unit area was greatest on the 900-sq. cm. and least on the 3,600-sq. cm. trap.

7.22. Heathcote, G. D. (1957). Effect of height on catches of aphids in water and sticky traps. *Plant Path.* **6**.

The numbers of aphids caught on yellow traps over bare ground decreased with increase in trap height from ground level to 152 cm. A water trap level with the tops of the plants in a potato field caught more than one at ground level among the plants. The early migrants of the chief species that transmit virus were few during the period of these experiments, but they were caught by both cylindrical and water traps.

7.23. Hirst, J. M. (1957). A simplified surface-wetness recorder. *Plant Path.* **6**, 57–61.

The spores of many plant pathogens need persistent water deposits in which to germinate and penetrate their hosts. An earlier balance continuously recorded changes in weight of external water on living shoots, but in this new instrument these are replaced by a block of expanded polystyrene, which makes it more suitable for routine use. Except during the early stages of

dew formation, these surfaces remained wet for the same time to within ± 1 hour, as did living apple shoots. Agreement was less close with potato foliage, perhaps because of different characters of the leaf surface, or because of the difficulty of exposing a single test surface so that it represents both the upper and lower leaves.

7.24. Hirst, J. M. & (Moore, W. C.) (1957). *Phytophthora infestans* on Petunia and Datura. *Plant Path.* **6**, 76.

Phytophthora infestans was found infecting Petunia and *Datura stramonium* out of doors in August 1956.

7.25. (Hollings, M.) & Kassanis, B. (1957). The cure of chrysanthemums from some virus diseases by heat. *J. R. hort. Soc.* **82** 339–342.

Chrysanthemum plants infected with seven different viruses were kept for 4 weeks at 36° C. and cuttings were taken at the end of this treatment. Infectivity tests have shown that several of the cuttings have been freed from tomato aspermy virus and from chrysanthemum stunt and ring pattern viruses, but none from an unidentified virus and from chrysanthemum B, D and vein mottle viruses.

7.26. Kassanis, B. (1957). The multiplication of tobacco mosaic virus in cultures of tumorous tobacco tissues. *Virology*, **4**, 5–13.

The concentration of tobacco mosaic virus in extracts from infected tobacco tumorous tissues is about $\frac{1}{5}\frac{1}{0}$ of that usual in sap from leaves of infected tobacco plants grown in soil. In constant conditions the virus concentration of tissues remains constant and is not influenced by their growth. Increasing the phosphate content of the medium increased the growth of the tissues but diminished the concentration of the virus, and diminished it more at high than at low concentrations of glucose. Virus concentration is not affected by increasing the nitrogen content of the medium. Some other substances affected the growth and some the virus concentration of the tissues, but there was no correlation between the two effects. The dry matter in extracts from the tissues is about the same as the dry matter of leaf sap, but there is much less protein in tissue extracts than in leaf sap.

7.27. Kassanis, B. (1957). The use of tissue cultures to produce virus-free clones from infected potato varieties. *Ann. appl. Biol.* **45**, 422–427.

By growing the excised apical meristems of sprouts from the potato varieties King Edward and Arran Victory, infected respectively with potato paracrinkle virus and potato virus S, virus-free plants were obtained. Although the method failed to produce virus-free plants from varieties infected with potato virus X, this virus also seems not to be present in apical meristems, for no virus could be demonstrated in callus tissue that developed from excised meristems less than 200 μ across. The concentration of tobacco mosaic virus in tomato roots and tobacco stems is also much less near the growing point than in older cells, but there is no evidence that the meristematic region is virus-free.

7.28. Kassanis, B. (1957). Some effects of varying temperature on the quality and quantity of tobacco mosaic virus in infected plants. *Virology*, **4**, 187–199.

From tobacco plants inoculated with isolates of virulent tobacco mosaic virus recently derived from single lesions, avirulent variants were readily obtained when the tobacco plants were maintained at 36° but not when they were maintained at 20°. The avirulent variants reached higher concentrations than the parent strain in plants kept at 36°. Both types reach much the same concentration in plants at 20°, and only occasionally can virulent variants be isolated from tobacco plants inoculated with the avirulent ones and kept at 20°.

The relative concentrations reached at 20° and 36° depend not only on the identity of the strain of tobacco mosaic virus used but also on the species of plant inoculated. Some strains seem unable to initiate infection in *Nicotiana*

glutinosa at 36°, although they persist at this temperature in cells that are infected at 20°.

Type tobacco mosaic virus is unstable in tobacco plants at 36°, and the virus content of sap slowly decreases when plants are kept at this temperature.

7.29. KASSANIS, B., TINSLEY, T. W. & (QUAK, FREDERIKA) (1958). The inoculation of tobacco callus tissues with tobacco mosaic virus. *Ann. appl. Biol.* **46**, 11–19.

Although cultures of normal and conditioned tobacco callus tissue occasionally became infected when dilute solutions of tobacco mosaic virus were poured over them, injuries were usually required, and the number of infections depended on the type and number of injuries. Tissues infected by superficial injuries usually became virus-free after sub-culturing, whereas those infected by needle-prick remained infected permanently. Although no plasmodesmata were found joining cells in the tissue cultures, tobacco mosaic virus moved between them at a rate of about 1 mm./week, approximately the same rate as it moves through cells of the leaf parenchyma.

7.30. KLECZKOWSKI, A. (1958). An electrophoretic study of the mechanism of precipitin reactions. *Immunology*, **1**, 36–45.

The compounds formed by tobacco mosaic virus and by human serum albumin with their antibodies were studied electrophoretically. Those formed by the virus at various antigen/antibody ratios in the reacting mixtures differed greatly in their electrophoretic mobility, which ranged from the mobility of free antigen to the mobility approaching that of free antibody. The differences in the mobility probably resulted from corresponding variations in antigen/antibody ratios in the compounds. By contrast, human serum albumin formed compounds of constant or nearly constant electrophoretic mobility irrespective of antigen/antibody ratios in the reacting mixtures, and when the precipitate formed at equivalence was dissolved in a solution of antigen, the amount of free antigen separated from the compound by electrophoresis was apparently the same as that in which the precipitate was dissolved. This and other evidence suggests that the albumin combined with its antibody at a constant ratio to form a compound that was stable during electrophoresis. The ratio was that of equivalence. More antigen combined with antibody when the antigen was in excess so that a soluble compound was formed, but then the combination was so loose that the compound dissociated during electrophoresis. The compound with the equivalence ratio was reconstituted and separated from free antigen by electrophoresis. It precipitated in the electrophoretic cell.

7.31. LAST, F. T. (1957). The effect of date of sowing on the incidence of powdery mildew on spring-sown cereals. *Ann. appl. Biol.* **45**, 1–10.

Delaying the date of sowing of spring-sown barley in 1953 and wheat in 1954 from February to April increased the incidence of powdery mildew, *Erysiphe graminis* DC., from May onwards. Before then, conditions did not favour the rapid spread of mildew.

From mid-June, infected barley produced necrotic lesions. These developed sooner on the early- than on the late-sown crops, and on the lower than upper leaves. Perithecia were first seen on 29 June. They were abundant on the wheat by 20 July.

Mildew reduced the yield of barley sown on 30 March and 28 April 1955 by 8 cwt./acre. The percentage loss was greater in the late- than in the early-sown crops. The number of ears per metre of row, the weight of 100 ears and the 1,000-grain weights were reduced. Altering the seed rate from 1½ to 2½ bushels/acre did not affect the incidence, or the effect, of mildew on grain yield.

7.32. SLOPE, D. B. (1957). *Opomyza florum* on early-sown winter wheat. *Plant Path.* **6**, 110.

Cappelle wheat sown in September, October, November and December had 8·0, 1·2, 0, 0·1 per cent shoots infested by larvae of *Opomyza florum* in May

1956 and 36·4, 8·6, 1·9, 1·6 per cent shoots infested in April 1957. The larvae mostly attacked late-formed tillers, and grain yields were not seriously decreased; in spite of the heavy infestations, early sown wheat yielded more than late.

Nematology Department

8.1. Fenwick, D. W. (1957). Preliminary studies on the effect of ethylene dibromide fumigation on the hatchability of *Heterodera rostochiensis* (Woll.). *Nematologica*, **2**, 242–249.

The effect of fumigation of *Heterodera rostochiensis* cysts on the hatchability of their egg contents was investigated. In a preliminary experiment at 20° C. and 100 per cent humidity in a saturated atmosphere of ethylene dibromide, hatchability was reduced and the point of inflection of the hatching curve occurred at 28 days for fumigated cysts compared with $7\frac{1}{4}$ days for controls. Similar results were obtained following fumigation at 15°, 20°, 25° and 30° C. If the hatching test was delayed several months, then hatchability was still further decreased and the delay in the attainment of the point of inflection was still apparent. These results indicate that hatching tests continued for a short fixed time may give misleading results, and it is suggested that tests should be carried on to completion.

8.2. Fenwick, D. W. (1957). Some experiments on the vacuum distillation of potato-root diffusate. *Nematologica*, **2**, 277–284.

Experiments were carried out on the stability of potato-root diffusate at different temperatures. Only negligible loss of activity resulted from 8 hours' exposure to 30° or 40° C. or 3 hours' exposure to 50° C. Laboratory distillation at 30–35° C. resulted in a reduction in volume to $\frac{1}{10}$ or $\frac{1}{20}$ of the original volume with an efficiency of about 80 per cent. In experiments carried out on a commercial scale at the University of Reading efficiency was very variable, but high levels were obtained on occasions. It is concluded that vacuum distillation is a practicable method of reducing diffusate volume for storage.

8.3. Franklin, M. T. (1957). Note on the nomenclature of the cereal-root eelworm. *Nematologica*, **2**, 149.

This note points out that the correct name of the cereal-root eelworm, according to the International Rules of Zoological Nomenclature, is *Heterodera major* O. Schmidt, 1930, and not *H. avenae* Mortensen, Rostrup & Kølpin Ravn, 1908.

8.4. Franklin, M. T. (1957). *Aphelenchoides composticola* n.sp. and *A. saprophilus* n.sp. from mushroom compost and rotting plant tissues. *Nematologica*, **2**, 306–313.

Descriptions of two new species of *Aphelenchoides* with characters distinguishing them from their nearest relatives are given.

8.5. Goodey, J. B. (1957). *Hoplolaimus proporicus* n.sp. (Hoplolaiminae: Tylenchida). *Nematologica*, **2**, 108–113.

The nematode is described and figured. It was found associated with the roots of the oil palm *Elaeis guineensis*, and is differentiated from all other species of *Hoplolaimus* in that there are no lateral fields, the annules going right round the body except at each end, where they are slightly interrupted in the lateral line.

8.6. (Hague, N. G.) & Hesling, J. J. (1958). Population studies on cyst forming eelworms of the genus *Heterodera*. *Proc. Linn. Soc.* **169**, 86–92.

The size of the initial population of *H. rostochiensis* and *H. major* has an important influence on the behaviour of these two eelworms. Low initial populations favour high eelworm increase, and vice-versa. The final eelworm population appears to rise to a maximum with increase of inoculum; further inoculum increase produces a final population lower than the maximum.

8.7. HESLING, J. J. (1957). The hatching response of *Heterodera major* (O. Schmidt) to certain root diffusates. *Nematologica*, **2**, 123–126.

Root diffusates of eight species of cereals and grasses (with soil water control) were tested for hatching activity on cysts of the cereal-root eelworm *H. major*. No stimulatory effect was observed.

8.8. HESLING, J. J. (1957). *Heterodera major* O. Schmidt 1930 on cereals—a population study. *Nematologica*, **2**, 285–299.

Oats, wheat and barley were grown in pots containing nine infestation levels (including control) of the cereal-root eelworm *H. major*. The height of the plants decreased with increase of the eelworm infestation, oats being most susceptible, followed by wheat and barley. Low initial infestation favoured high eelworm increase; this was greatest in oats, followed by barley and wheat. Barley produced relatively more large cysts. Relatively more small cysts were produced from the high infestation level, but cysts of the same size had similar egg content irrespective of the infestation level from which they were derived.

8.9. JONES, F. G. W. (1957). Resistance-breaking biotypes of the potato-root eelworm (*Heterodera rostochiensis* Woll.). *Nematologica*, **2**, 185–192.

Tests made with populations of potato-root eelworm from twenty localities indicate that biotypes capable of breaking the resistance of *Solanum tuberosum* ssp. *andigena* and of crosses between the above and *S. tuberosum* ssp. *tuberosum* occur widely. In the populations tested the percentage of resistance-breaking females ranged from less than 1 to 75 per cent. Slight evidence of the breakdown of resistance in first backcrosses was obtained in one population.

8.10.* JONES, F. G. W. (1957). Soil populations of beet eelworm in relation to cropping. III. Further experiments with microplots and with pots. *Nematologica*, **2**, 257–272.

Further experiments with beet eelworm (*Heterodera schachtii* Schm.) in microplots are described. Four years' results from a rotational experiment are given, together with criticisms of the lay-out. An experiment was conducted in a peaty clay soil to test the effects of three host plants (sugar beet, cress and charlock) when grown at different population levels. All treatments caused a fall in population level. At the end of the experiment cyst and egg populations were highest after cress and lowest after charlock; they were also highest at the higher plant population levels, but the differences were mainly insignificant. The effects of a range of host plants was tested on a plant-for-plant basis in two types of fine sandy loam. That containing an appreciable coarse fraction (19 per cent) gave no response, but that containing a very fine fraction bordering on silt (74 per cent) gave increases with most Chenopodiacious and Cruciferous hosts. In a pot experiment using low inoculum levels, a significant increase in yield occurred at the lowest inoculum level, and there was a significant inverse regression between yield and log inoculum level. The maximum population increases were 19 times and 84 times for cysts and eggs respectively at the lowest inoculum level. There was no evidence of a " ceiling " effect. The difference in behaviour of the beet-eelworm populations in the microplot soils may be due to soil structure/moisture relationships, but also possibly to biological properties.

8.11. MURPHY, P. W. & DONCASTER, C. C. (1957). A culture method for soil meiofauna and its application to the study of nematode predators. *Nematologica*, **2**, 202–214.

For summary see below No. 10.14.

8.12. WALLACE, H. R. (1957). The stimulatory properties of some organic substances on cysts of the beet eelworm, *Heterodera schachtii* Schmidt. *Ann. appl. Biol.* **45**, 251–255.

Techniques for determining the influence of various substances on the rate of larval emergence from cysts of the beet eelworm are described. There

* Work begun in the School of Agriculture, University of Cambridge.

is no significant difference between the rates of larval emergence in glutamic acid, galactinol, inosotol and water; the rate of larval emergence in beet diffusate, on the other hand, was significantly higher. Studies of larval emergence in carbohydrates suggest that the cyst population used in the experiments was heterogeneous, consisting of two types of cyst which have different reactions to stimulation at different concentrations. The significance of root exudates in relation to beet eelworm is discussed.

8.13. Wallace, H. R. (1957). Movement of eelworms. I. The influence of pore-size and moisture-content on the migration of larvae of the beet eelworm, *Heterodera schachtii* Schmidt. *Ann. appl. Biol.* **46**, 74–85.

Experiments on vertical migration through saturated soil fractions, horizontal migration through soil fractions at different suctions and migration in single layers of particles showed that the beet eelworm, *Heterodera schachtii* Schmidt, attained maximum speed when the pore diameters were between 30 and 60 μ. Speed of the eelworms increased as lateral displacement of the body was restricted by external resistances acting perpendicularly to the body axis; at the maximum speed there was no lateral movement, each part of the body following the part immediately in front of it. The speed of beet-eelworm larvae in water films of various thickness was measured; maximum speed occurred in a film 2–5 μ thick. Four arbitrarily classified types of progression were observed in the pore spaces. It is suggested that the " moisture characteristic " supplies most of the information required about the physical properties of the soil in relation to eelworm movement. By examining such a curve the pore-size distribution and water distribution can be ascertained and the probable behaviour of beet-eelworm larvae in the medium predicted.

8.14. Widdowson, E. (1958). Potato-root diffusate production. *Nematologica*, **3**, 6–14.

Pot tests are described in which the effects of age, variety and an infestation of potato-root eelworm were observed on the root diffusate production of potatoes. The plants were grown in 6½-inch pots of coarse sand and leached with 250 ml. of water. The most active diffusate was produced up to 4 weeks after the emergence of the shoot, a period of very rapid root growth. After 6 weeks the activity of the diffusate declined. Ten commercial potato varieties were compared and gave diffusates of approximately the same activity; with the varieties Eclipse and Majestic the most active and Duke of York and King Edward the least active in two seasons. When potatoes were grown in sand artificially inoculated with 21, 45 and 102 eggs/g. of potato-root eelworm, increased diffusate output was observed from the plants at the medium and low levels. Although the high population level caused the most root growth up to 6 weeks from the emergence of the shoot in both seasons, there was no corresponding increase in diffusate production; in fact, in the second season it was reduced. A comparison between potatoes and tomatoes showed that potatoes produced the most diffusate per unit weight of root up to 2 weeks after emergence of the potato shoot, with an indication that tomatoes produced more after 9 weeks.

8.15.* Winslow, R. D. & (Ludwig, R. A.) (1957). Studies on hatching stimulation in the beet eelworm, *Heterodera schachtii* Schmidt. *Canad. J. Bot.* **35**, 619–634. (Contribution No. 106, Science Service, Laboratory, Canada Department of Agriculture, London, Ont.)

Hatching of the beet nematode from Ontario beet fields was stimulated by root diffusates from host plants. Various aspects of the production of potent diffusates from rape and beet plants and germinating rape seedlings were investigated. Tops, roots and various root portions from rape seedlings all produced stimulatory substances. The concentration of diffusates by vacuum distillation and attempted extraction of the active principle with charcoal, phenol, 1-butanol and ion exchange are described.

8.16.* Winslow, R. D. & (Williams, T. D.) (1957). Amoeboid organisms attacking larvae of the potato root eelworm (*Heterodera rostochiensis* Woll.) in England and the beet eelworm (*H. schachtii* Schm.) in Canada. *Tijdschr. PlZiekt.* **63**, 242–243.

Amoeboid organisms were found attacking *Heterodera rostochiensis* in England and *H. schachtii* in Canada, the attacks occurring on larvae emerging from cysts in water or root diffusate in glass dishes in the laboratory. The English form was recovered with potato-eelworm cysts from two locations in Feltwell Fen, Norfolk, and the Canadian form with eelworm cysts from a field infested with *H. schachtii* in the Blackwell district, Essex County. The organisms appear very similar to *Theratromyxa weberi* Zwillenberg; slight differences between the behaviour of the English and Canadian organisms and the latter may be due to differences in cultural conditions.

8.17. (Wood, F. C.) & Goodey, J. B. (1957). Effects of gamma ray irradiation on nematodes infesting cultivated mushroom beds. *Nature, Lond.* **180**, 760–761.

Mushroom compost infested with *Ditylenchus* sp. and *Rhabditis* sp. was irradiated by gamma rays. The nematodes were counted before and after treatment and their rates of reproduction assayed on mushroom compost and agar plates sown with yeast. Doses between 48,000 and 96,000 reps inhibited reproduction of both species.

Insecticides Department

General Papers

9.1. McIntosh, A. H. (1957). Temperature and toxicity of insecticides. *Chem. & Ind.* 2–4.

Research Papers

9.2. Broadbent, L., Burt, P. E. & (Nix, J. S.) (1957). The cost of using insecticides to maintain the health of potato seed in England and Wales. *N.A.A.S. Quart. Rev.*

For summary see above No. 7.11.

9.3. Buxton, E. W., Last, F. T. & Nour, M. A. (1957). Some effects of ultraviolet radiation on the pathogenicity of *Botrytis fabae*, *Uromyces fabae* and *Erysiphe graminis*. *J. gen. Microbiol.* **16** (3), 764–773.

For summary see above No. 7.16.

9.31. Elliott, M. (1956). The preparation of *cyclo*pentenones from the products of Stobbe condensations with aliphatic ketones. *J. chem. Soc.* 2231–2241.

9.4. McIntosh A. H. (1957). Particle size of insecticidal suspensions and their contact toxicity. VI. Effect of temperature on relative toxicity. *Ann. appl. Biol.* **45** (1), 189–205.

Two aqueous suspensions, one containing crystals of uniform size and the other containing colloidal particles, were made with each of seven solid contact poisons (two DDT-analogues, DDT, rotenone, 2-bromomercurithiophen, dieldrin and endrin). The relative toxicity of each pair of suspensions was found in dipping or measured-drop tests on as many as possible of the species *Oryzaephilus surinamensis* L., *Tribolium castaneum* Herbst and *Tenebrio molitor* L. In addition, some tests were made by injection of colloidal suspensions.

* Work done in Canada.

In each test, insects were kept after treatment at two temperatures: 28° C. and 11°, 17° or 20° C.; counts of kill were made after 24 hours. The tests measured three different kinds of temperature coefficient of insecticidal action.

In the contact tests, the colloid was nearly always more toxic than the crystals. In all the tests, except those with dieldrin, the relative toxicity (colloid : crystals) was greater at the lower after-treatment temperature, i.e., the *temperature coefficient of the relative toxicity* was negative. But in the case of dieldrin, the coefficient was positive.

The DDT-analogues, DDT, rotenone and endrin were more toxic at the lower after-treatment temperature, i.e., they had negative *temperature coefficients of kill by contact action*. In all these cases the temperature coefficient of kill by contact action was greater for colloid than for crystals. Dieldrin and 2-bromomercurithiophen had positive temperature coefficients of kill by contact action. With dieldrin, the temperature coefficient was greater for colloid than for crystals; but with 2-bromomercurithiophen, the reverse was true.

The *temperature coefficient of kill by injection* was negative for DDT, but positive for dieldrin and endrin; the other poisons were not tested by injection.

A possible explanation for the results of the contact tests is given in an Appendix. The explanation is based on a number of assumptions about the penetration of insect cuticle by solid poisons. These assumptions lead to the conclusion that the effect of temperature on the relative toxicity depends on the temperature coefficient of kill by internal action of the poison on the insect. This can be measured by injection tests. If it is negative or zero, the ratio of toxicities (colloid : crystals) by contact action, measured quite soon after treatment of the insects, will be greater at a low temperature after treatment than at a high temperature after treatment; but if the coefficient is positive, the effect of temperature on relative toxicity cannot be foretold. The experimental results seem to confirm the assumptions.

9.5. Potter, C. & Gillham, E. M. (1957). Effect of host-plant on the resistance of *Acyrthosiphon pisum* (Harris) to insecticides. *Bull. ent. Res.* **48**, 317–322.

By means of a laboratory spraying technique, ten comparisons were made of the resistance to rotenone of samples of adult apterous viviparous parthenogenetic females of the Pea Aphid, *Acyrthosiphon pisum* (Harris), reared on broad bean and on clover, respectively. In nine of the tests, the Aphids from clover were more resistant than those from broad bean, the ratios ranging from 1·1 to 2·5. These differences were not all significant. In the remaining test the Aphids from broad bean showed a very small increase in resistance over the Aphids from clover, which was not significant.

The Aphids from the clover were generally smaller than those from broad bean. Figures are given to show that while the total amount of poison retained by the larger individuals from broad bean was more than that retained by the smaller individuals from clover, the amount of poison retained per unit body weight was greater with the smaller individuals. It appears, therefore, that while the results obtained might be due, at least partially, to the greater total weight of poison retained by the larger individuals from broad bean, the difference in resistance between the insects from broad bean and clover, respectively, might be even greater if the poison were applied on the basis of equal weight of poison per unit of body weight. Since the difference in resistance between the Aphids from the two host-plants did not appear to depend primarily on difference in size, the assumption might be made that it is due to difference in nutrition. It was found that Aphids reared on clover had a significantly higher proportion of dry matter in their composition than those reared on broad bean, which may be taken as evidence that differences due to nutrition are being produced. These may lead to differences in resistance.

9.6. Potter, C., Lord, K. A., Kenten, J., Salkeld, E. H. & Holbrook, D. V. (1957). Embryonic development and esterase activity of eggs of *Pieris brassicae* in relation to TEPP poisoning. *Ann. appl. Biol.* **45**, 361–375.

The embryological development of eggs of *Pieris brassicae* was studied in relation to the occurrence of enzymes hydrolysing phenyl acetate and acetylcholine. Phenyl acetate is hydrolysed at a high rate at all stages of develop-

ment of the embryo. Hydrolysis of acetylcholine only becomes appreciable in the later stages of development. The first significant level of hydrolysis of acetylcholine can be correlated with the development of a nervous system in the embryo to a stage where it may be functional.

Aqueous solutions of TEPP were applied to eggs soon after they were laid. Low doses of TEPP allowed a high percentage of eggs to develop to the point of hatching before death occurred. Most fully developed embryos became active before they died. As the dose was increased less development took place and with very high doses little development occurred.

The significance of these results is discussed. The available evidence does not indicate that the poison penetrates slowly nor that it is "locked up" and later released. The explanation that seems to fit the evidence best is that the poison penetrates rapidly and reacts irreversibly with, probably phosphorylates, one or more components of the egg, the extent of subsequent development depending upon the proportion of a biochemical system or the number of systems inactivated. Whilst inhibition of cholinesterase may play a part in the poisoning process, at least under some conditions, the evidence indicates that the death of the embryo may result from some other cause.

9.7. Raw, F. & Potter, C. (1958). Studies on the chemical control of wireworms (*Agriotes* spp.). II. Direct and residual effects of BHC, DDT, aldrin and chlordane. *Bull. ent. Res.* (In the press.)

For summary see below No. 10.18.

9.8. Way, M. J. & Needham, P. H. (1957). Control of some bean and potato pests using a systemic insecticide applied to the soil and seed. *Plant Path.* **6**, 96–103.

A systemic insecticide used as a seed dressing or drilled with the seed can subsequently kill insects attacking the aerial parts of the plant (Andersson and Ossiannilsson, 1951; Ashdown and Cordner, 1952; Unterstenhöfer, 1953). This paper gives results of field experiments with the systemic insecticide demeton applied at sowing time for control of the black bean aphid *Aphis fabae* Scop., the vetch aphid *Megoura viciae* Buckt., the green peach aphid *Myzus persicae* Sulz. on potatoes and the pea and bean weevil *Sitona lineatus* L. on field beans.

Entomology Department

Research Papers

10.1. Dobson, R. M., Stephenson, J. W. & Lofty, J. R. (1957). Quantitative studies of adult populations of Wheat bulb fly, *Leptohylemyia coarctata* (Fall) in the field. *Ann. appl. Biol.* **45**, 385–386.

10.2. French, R. A. (1957). Migration records for 1956. *Entomologist*, **90**, 227–238.

10.3. Haine, E. (1957). Periodicity in aphid moulting and reproduction in constant temperature and light. *Z. angew. Ent.* **40**, 100–124.

Preliminary experiments on the moulting rates of *Aphis fabae*, *Myzus persicae* and *Neomyzus circumflexus* suggested that there might be a diurnal rhythm even in constant conditions. Further extensive experiments on moulting in *A. fabae* gave a significant depression of numbers at about midday. Both parturition and moulting in *M. persicae*, with several different pretreatments, were found to produce rhythmic rates which changed significantly at certain times. However, coincidence of such changes in processes so different as parturition and moulting, and coincidence in changes in the same process between different species, suggests strongly that the rhythm was imparted by external conditions. The insects must have been very sensitive to these environmental factors, which could not be detected.

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10.4. JOHNSON, BRUCE (1954). The flight capacity of aphids in relation to the spread of viruses. *Proc. 2nd Conf. Potato Virus Diseases*, 70–74.

The life of the alate *Aphis fabae* consists of two distinct stages: when they are young and can fly, and when they are settled down on a host plant and have lost the ability to fly. The transition from one stage to the other, settling, is affected by the aphids' previous experience, i.e., the amount of flight undergone and the number of previous alightings, the quality of the host upon which it settles, the weather which may make further take-off impossible and the extent to which the aphid has progressed towards flight-muscle histolysis.

10.5. JOHNSON, BRUCE (1956). Function of the antennae of aphids during flight. *Aust. J. Sci.* **18**, 199–200.

The flight reflex of alate aphids can readily be stimulated by dropping them, or by a slight puff of air when they are suspended on a pin. By amputating various parts of the antennae, replacing with artificial antennae and by sealing the joints with paint it was shown that the site of sensorial response is between the second and third segments, where the intersegmental membrane is innervated by the Johnston's organ.

10.6. JOHNSON, BRUCE (1957). Studies on the degeneration of the flight muscles in alate aphids. I. A comparative study of the occurrence of muscle breakdown in relation to reproduction in several species. *J. Insect Physiol.* **1**, 248–256.

When alate aphids of several species were allowed to settle down on their host plants their flight muscles began to break down within a few days The onset of muscle degeneration could be delayed by preventing the aphids from settling down, either by denying them their host altogether or by leaving them on a poor host in darkness for several days.

The reproductive capacity of alatae before they lost the ability to fly varied for different species. Embryo development was arrested in alatae of all the species that were studied after the end of the teneral condition following final ecdysis, and was resumed when they settled down on a new host. Some species of aphids contained a number of fully formed embryos at the time embryo development was arrested, and these plus a few additional embryos whose development had been completed after the aphids settled down were born before the ability to fly was lost. In other species the young alatae contained only rudimentary embryos that required several days to develop to the stage at which they were normally born; in these species no larvae were born until the muscles had begun to degenerate and the ability to fly was lost. Other species fell between these two groups and in one species, *Macrosiphum euphorbiae* (Thomas), whether or not the aphids reproduced at all before losing the ability to fly, depended upon their size.

The ability of alatae of *Aphis fabae* Scop. to engage in long flights of 1 hour or more was retained for as long as the aphids retained the ability to fly.

10.7. JOHNSON, C. G. (1957). The vertical distribution of aphids in the air and the temperature lapse rate. *Q. J. R. met. Soc.* **83**, 194–201.

Aphid density diminishes with height above the ground; the linear regression coefficient, $-b$, of log density on log height is an approximate expression of the vertical density profile. A low negative value of b suggests a relatively high degree of upward transport, and a high value the reverse.

From May to October 1948 aphid densities were estimated simultaneously at heights from 50 to 2,000 feet over 2-hour periods during the day: lapse rates to 2,000 feet were also measured. The regression coefficient, $-b$, of log density on log height was inversely correlated with the mean lapse rate between months; September and October were associated with low lapse rates and steep density gradients.

Correlation coefficients of b with lapse for 2-hour periods were negative above a lapse of 10° F./2,000 feet, and became statistically significant in the afternoon. Below the 10° F. value no significant correlation existed, probably

because low lapse rates occurred usually in the early morning when densities were low and factors other than atmospheric mixing could affect the profile.

Two examples of the change in the vertical profile from hour to hour throughout the day are given to illustrate the association of high lapse rates with high-altitude dispersal and the limitation of upward transport when lapses are low; but biological factors also play a part in determining the form of the profile, and these are briefly discussed.

10.8. Johnson, C. G. (1957). The distribution of insects in the air and the empirical relation of density to height. *J. anim. Ecol.* **26**, 477–492.

The main data of Hardy and Milne, Glick, Freeman and Johnson, giving insect density at various heights, have been fitted to the empirical formula $f(z) = C(z + z_e)^{-\lambda}$, where $f(z)$ is insect density at height z, C is a scale factor related to population size, λ is an index of the rate of diffusion and z_e is a constant specific to each set of data. This shows that the distribution process is continuous up to thousands of feet, and integration enables the total numbers of insects between given heights to be assessed.

10.9. Johnson, C. G., Haine, E., Cockbain, A. J. & Taylor, L. R. (1957). Moulting rhythm in the alienicolae of *Aphis fabae* Scop. (Hemiptera: Aphididae) in the field. *Ann. appl. Biol.* **45**, 702–708.

In a natural population of alienicolae of *Aphis fabae* Scop. on field beans in July 1952, the frequency of moulting of the last larval instar into the alate form was usually relatively high between about 0400 and 0800 hours G.M.T. This high rate was followed by a decline to a lower fluctuating rate for the rest of the day. The moulting rate at night was usually very low.

Changes in moulting rate during the rest of the day are correlated with temperature and with time, both independently. A rise of 1° C. ambient temperature is associated with an 11·6 per cent rise in moulting rate; a fall of 1° C., with a drop of 10·5 per cent and a lapse of 1 hour in time by a 5·4 per cent drop in the rate. Sunshine and humidity show no simple correlation with moulting rate.

10.10. Johnson, C. G. & Taylor, L. R. (1957). Periodism and energy summation with special reference to flight rhythms in aphids. *J. exp. Biol.* **34**, 209–221.

Summer populations of *Aphis fabae* often show a bimodal curve of flight activity. The origin of the two peaks of activity is quite distinct.

Flight takes place, weather permitting, at the end of a variable interval (the teneral period) after the final moult. The lengthening and shortening of this period with the daily fluctuations in temperature produces a unimodal curve of " flight mature " aphids with its peak in the afternoon. A graphical method for the integration of the daily temperature curve, after conversion by the response curve of the aphid, to produce this " flight maturity curve " from either a constant or measured moulting rate, is given.

But aphids will not fly in the dark or at low temperatures, hence those maturing after dark will wait until temperature rises to their threshold in the morning. This threshold appears in a population as a frequency distribution against temperature, and has been measured in laboratory experiments. The morning peak of flight consists of those aphids which were delayed overnight taking flight in a peak shaped according to this frequency distribution.

Thus the apparent flight periodicity of aphids is purely a population phenomenon. The aphids take-off once and leave the vicinity, and only by the synchronization of this single act within the population is a periodicity apparent. The synchronization is due to an energy limited developmental process, and is periodic only because temperature is diurnally periodic. The process could equally well apply to seasonally periodic processes, such as population growth and decline, or to the period activity of organs in which the development or secretion of a population of cells is energy dependent and the energy supply (light or heat) is periodic.

10.11. Johnson, C. G., Taylor, L. R. & Haine, E. (1957). The analysis and reconstruction of diurnal flight curves in alienicolae of *Aphis fabae* Scop. *Ann. appl. Biol.* **45**, 682–701.

The relationship of teneral period to temperature, together with the measured rate of moulting and a continuous record of temperature, have been used to construct theoretical daily curves for numbers flying from a bean crop. These curves have been matched against the observed curves for the same days.

The differences between curves so constructed for a period of 17 days and the observed curves for the same period are of the same order and kind as the differences between two measured curves in different sites at the same time.

The different types of daily flight curve can thus be accounted for in terms of the rate of production of alatae by moulting, the effect of temperature on the teneral ("drying out") period and the effect of low light intensity and temperature on take-off behaviour.

10.12. Long, D. B. (1957). Oviposition of Wheat Bulb Fly, with special reference to crop and site selection. *Ann. appl. Biol.* **45**, 388.

10.13. Murphy, P. W. (1957). Soil faunal investigations. *For. Comm. Rept. For. Res.*, 1955–56, 91–94.

10.14. Murphy, P. W. & Doncaster, C. C. (1957). A culture method for soil meiofauna and its application to the study of nematode predators. *Nematologica*, **2**, 202–214.

Methods for culturing Acarina, Collembola and other small soil animals are reviewed, and two new types of culture chamber described. One of these is particularly suitable for collecting live material from litter and soil with a funnel-type extractor.

Laboratory observations were made of Collembola as predators of free-living and plant-parasitic nematodes, especially *Heterodera cruciferae*. At least 9 per cent of *H. cruciferae* cysts in a pot culture were found to have been damaged by Collembola. *Isotoma viridis*, *Hypogastrura* sp., *Orchesella villosa* and *Onychiurus armatus* were observed feeding on cysts of *H. cruciferae*. The last named, the most important predator cultured, also fed on inactive nematodes of the genera *Dorylaimus* and *Mononchus*.

10.15. Nijveldt, W. (1957). Aphid-eating Gall Midges (Cecidomyidae) with special reference to those in the Barnes collection. *Ent. Ber.* **17**, 233–239.

10.16. Raw, F. & Lofty, J. R. (1957). Estimating crop losses due to Wheat Bulb Fly. *Plant Path.* **6**, 51–56.

An estimate of the crop losses caused by an insect is necessary when assessing its economic importance. In practice, an estimate is difficult to make because of the difficulty of establishing different levels of infestation experimentally. It is shown that this can be done without using insecticides or affecting conditions for plant growth by utilizing the oviposition response of wheat-bulb fly to certain soil conditions and by screening plots to prevent oviposition. Data from experiments of Broadbalk and Pennell's piece are presented to show how crop losses can be estimated in this way.

10.17. Raw, F. & Stokes, B. M. (1958). Field observations on the infestation of alternative host plants by wheat bulb fly. *Plant Path.* (In the press.)

A small, relatively isolated, fallow plot was found to have an infestation of about eleven wheat-bulb-fly eggs per square foot. Weeds and grasses, some of them known or suspected host plants of wheat-bulb fly, germinated in the fallow, but plant counts revealed an extremely low infestation rate. These observations support the results of pot experiments, which suggest that some alternative host plants are less readily infested than winter wheat.

10.18. Raw, F. & Potter, C. (1958). Studies on the chemical control of wireworms (*Agriotes* spp.). II. The direct and residual effects of BHC, DDT, aldrin and chlordane. *Bull. ent. Res.* (In the press.)

An account is given of an experiment carried out on Geescroft Field, Rothamsted, from 1951 to 1954 to investigate the direct and residual effects of BHC, DDT, aldrin and chlordane applied to control wireworm damage to wheat.

In the year of application, the first out of old grass, when wireworm attack was slight, the plots treated with BHC, aldrin and chlordane combine-drilled gave significantly greater yields than the control plots. In the following year when wireworm attack was heavier, residual effects on yield were observed on plots initially treated with BHC, DDT, aldrin and chlordane combine-drilled. The next year residual effects on yield were observed on the plots initially treated with BHC and aldrin combine-drilled.

No direct or residual effect of BHC seed dressing was observed.

The residual effects are closely associated with the effect of the treatments on the wireworm population.

The results are compared with those of previous experiments, and the economic returns from the various treatments are discussed briefly.

10.19. Southwood, T. R. E. (1955). The morphology of the salivary glands of terrestrial Heteroptera (Geocorisae) and its bearing on classification. *Tijdschr. Ent.* **98**, 77–84.

The structure of the salivary glands depends more on the taxonomic relationship of the species than on feeding habits or on the nature of the secretions, and the use of salivary-gland structure in higher classification is proposed. Accessory glands are diagnostic for each of the basic divisions of terrestrial Heteroptera, the Pentatomomorpha possessing tubular and the Cimicomorpha vesicular accessory glands. Some suggested characteristics of the salivary glands of most superfamilies and families in the Geocorisae are given.

10.20. Southwood, T. R. E. (1956). The structure of the eggs of the terrestrial Heteroptera and its relationship to the classification of the group. *Trans. R. ent. Soc. Lond.* **108**, 163–221.

The development, structure and hatching of the eggs of the terrestrial Heteroptera are shown to support the division of the Geocorisae (*sensu* Dufour, 1833) into the Pentatomomorpha and Cimicomorpha. The micropylar apparatus is of two types, the micropylar processes of the Pentatomomorpha and the pseudomicropyles and true micropyles of the Cimicomorpha. A true operculum is present only in the Cimicomorpha. The Pentatomomorphan egg normally lacks a distinct egg cap, but when one is present it is not homologous with the operculum of the Cimicomorpha and is called a pseudoperculum. Hatching spines and ridges are present in both the Pentatomomorpha and Cimicomorpha, but a median egg-burster is confined to the Pentatomomorpha.

From the present work and that of earlier authors structural characteristics of the egg are given for each family and many subfamilies. It is suggested that this evidence from egg structure should be considered, together with other evidence, when discussing the status of various groups and their phylogenetic relationships.

10.21. Southwood, T. R. E. & Johnson, C. G. (1957). Some records of insect flight activity in May 1954, with particular reference to the massed flights of Coleoptera and Heteroptera from concealing habitats. *Ent. Mon. Mag.* **93**, 121–126.

10.22. Southwood, T. R. E. & Scudder, G. G. E. (1956). The bionomics and immature stages of the Thistle Lace Bugs (*Tingis ampliata* H.-S. and *T. cardui* L.; Hem., Tingidae). *Trans. Soc. Brit. Ent.* **12**, 93–112.

10.23. Southwood, T. R. E. & Scudder, G. G. E. (1956). The immature stages of the Hemiptera–Heteroptera associated with the stinging nettle (*Urtica dioica* L.). *Ent. Mon. Mag.* **93**, 313–325.

10.24. Stokes, B. M. (1957). Laboratory experiments on larval behaviour on Wheat Bulb Fly. *Ann. appl. Biol.* **45**, 386–387.

10.25. Stokes, B. M. (1957). *Mayetiola dactylidis* Kieffer in cocksfoot grass. *Plant Path.* **6**, 127–130.

10.26. Taylor, L. R. (1957). Temperature relations of teneral development and behaviour in *Aphis fabae* Scop. *J. exp. Biol.* **34**, 189–208.

Experiments in which alate aphids were marked immediately after emergence and observed until they took flight showed that this interval, called the teneral period, is usually related to temperature by a curve of the form typical of developmental processes. This is true for the fluctuating temperatures found in the field, and was confirmed at constant and varying temperatures in the laboratory. Other climatic factors were found to have no distinguishable effect. The variation due to individual aphids is a constant proportion of the mean teneral time at all temperatures. The behaviour of aphids towards the end of the teneral period has a typical pattern, and it is found to be closely similar in other insects.

Flight may be delayed in aphids if the teneral period ends in darkness or low temperature. This is due to the take-off behaviour of the insect, and the thresholds for activity are shown by trap catches. Behaviour and development are separated by inspection at each stage in the analysis which is by successive approximation.

10.27. Taylor, L. R. (1957). Aphid dispersal and diurnal periodicity. *Proc. Linn. Soc. Lond.* **169**, 67–73.

The periodic nature of aphid flight activity over a host crop depends upon processes in the development of the flight-immature individuals of the population; the flying aphids are only a few hours old. Since the total aerial population up to thousands of feet shows similar periodic fluctuations, it therefore appears that the aphids, however high they reach, fly only for a very few hours.

Locust swarms maintain themselves by the constantly repeated take-off of the individuals after landing. It appears that the circulatory processes responsible for taking up aphids and locusts are similar and the difference in sustaining aerial activity is largely a function of behaviour. There is some observational evidence for this.

The first problem of wind-assisted dispersal of this kind is to cross the "boundary layer" of relatively still air near the ground at take-off. This is a problem common to insects and spores, although the layer is of different depth and is defined in different ways.

Bee Department

General Papers and Reviews

11.1. Bailey, L. (1957). Comb fumigation for Nosema disease. *Amer. Bee J.* **97**, 24–26.

A method of fumigation, with acetic acid vapour, of combs contaminated with spores of *Nosema apis* is described. The results of a 3-year experiment on the control of *Amoeba* disease are also given, and it is shown that this latter disease can be effectively controlled by the same methods as *Nosema* disease.

11.2. Butler, C. G. (1957). Some work at Rothamsted on the social behaviour of honeybees. [Lecture.] *Proc. roy. Soc. B*, **147**, 275–288.

A brief review of some of the work carried out in recent years in the Bee Department on the social behaviour of honeybees.

11.3. Butler, C. G. (1957). Beekeeping. *Bull. Min. Agric. Fish. & Food*, **9**.

A revision of the Bulletin written by C. G. Butler and first published in 1945.

11.4. Simpson, J. (1958). The factors which cause colonies of *Apis mellifera* to swarm. [Lecture.] *Insectes soc.* (In the press.)

Research Papers

11.5. Bailey, L. (1957). The cause of European Foul Brood. *Bee World*, **38**, 85–89.

Results of infection experiments made in 1956 are given. Disease was repeatedly caused in healthy colonies by spraying their brood with suspensions of *Streptococcus pluton* + *Bacterium eurydice*; these organisms having been grown in a mixed culture. Simultaneous infection with pure cultures (fifth subcultures) of each of these organisms did not cause disease. Disease appeared on one occasion after the comb, which had been inoculated with a pure culture of *S. pluton*, was twice resprayed with watery suspensions of larvae taken from the comb 5 and 10 days after inoculation. However, *B. eurydice*, as well as *S. pluton*, was then isolated from the diseased larvae. This made it appear that healthy colonies may contain *B. eurydice*, but as this organism had not been isolated from such colonies, it was concluded that its distribution was likely to be sparse.

11.6. Bailey, L. (1957). The isolation and cultural characteristics of *Streptococcus pluton* and further observations of *Bacterium eurydice*. *J. gen. Microbiol.* **17**, 39–48.

Details of the way in which *Streptococcus pluton* was eventually isolated are given. The organism normally grows anaerobically as a lanceolate coccus, but can be trained to grow aerobically, which it does in the form of a thick rectangular rod. Its anaerobic cultural requirements are very critical, but the aerobic rod will grow on ordinary media. *Bacterium eurydice* was found to be quite distinct in its cultural characteristics from *S. pluton*; its anaerobic growth is greatly enhanced by glucose + fructose (or honey); either sugar alone supports only feeble anaerobic growth.

11.7. Bailey, L. (1957). European Foul Brood: a disease of the larval honeybee (*Apis mellifera* L.) caused by a combination of *Streptococcus pluton* (*Bacillus pluton* White) and *Bacterium eurydice* White. *Nature, Lond.* **180**, 1214–1215.

The use of honey in the culture media facilitated the early separation of *Streptococcus pluton* and *Bacterium eurydice* into pure cultures. An infection experiment was carried out with second subcultures of the organisms; either organism alone did not cause disease, but a mixture of the two caused extensive European Foul Brood disease.

11.8. Butler, C. G. (1957). The process of queen supersedure in colonies of honeybees (*Apis mellifera* L.). *Ins. soc.* **4**, 211–223.

In the process known as "queen supersedure" the workers of a colony rear a new queen in the presence of the old one, without swarming. Various suggestions that have been made to account for this process are examined and shown to be untenable. It is demonstrated that a queen, who had actually been superseded by her workers, was nevertheless capable of inhibiting queen rearing in small, but not in large, colonies. Since it has been shown that a substance which workers obtain from their queens (queen substance) inhibits them from rearing further queens, provided that the quantity is sufficient

for the number of bees present in their colonies, it is probable that this queen was producing insufficient queen substance to inhibit queen rearing in a large colony. It is concluded that shortage of queen substance is the only *immediate* cause of queen supersedure, and that any other factors which tend to cause a queen's supersedure do so by reducing her output of queen substance.

11.9. Butler, C. G. (1957). The control of ovary development in worker honeybees (*Apis mellifera*). *Experientia*, **13**, 256–258.

The results are given of experiments which demonstrate that an acetone extract of a queen honeybee is sufficient to inhibit development of the ovaries of a group of queenless worker bees when added to their food. In order to be effective it does not have to be presented to them on the body of a dead worker bee or other queen-like object as has been suggested.

11.10. Butler, C. G. & Gibbons, Doreen A. (1958). The inhibition of queen rearing by feeding queenless worker honeybees (*A. mellifera*) with an extract of "queen substance". *J. Insect Phys.* **2**. (In the press.)

It is demonstrated that the residue from an ethanol extract of queen honeybees (i.e., of "queen substance") is, when given to queenless worker honeybees, either in sugar syrup on the bodies of dead worker bees or in distilled water in a gravity feeder, sufficient to inhibit them from attempting to rear a new queen.

11.11. Free, J. B. (1957). The food of adult drone honeybees (*Apis mellifera*). *Brit. J. Anim. Behav.* **5**, 7–11.

For the first few days of their lives, drones are fed entirely by workers. This is followed by a period in which they are both fed by workers, though not to such an extent as previously, and also feed themselves from honey cells. After they are about a week old they tend to feed themselves entirely and do not beg food from workers.

Worker bees 2–26 days old were seen to feed drones, although those 4–6 days old were the most active in so doing. It is most probable that the workers feed drones with brood food.

The behaviour of a worker towards a drone appears to depend on his age; at the same time as some of the older drones in a colony are being attacked by workers, the younger drones present are still being fed. The workers who attack drones are probably unemployed foragers.

11.12. Free, J. B. (1957). The transmission of food between worker honeybees. *Brit. J. Anim. Behav.* **5**, 41–47.

There is a general tendency for food to pass from the older to the younger workers of a colony, although there is a considerable passage of food in the opposite direction. Younger bees generally receive food more frequently than they give it. As worker bees grow older the mean ages of the bees who feed them and to whom they give food also increase. When undertaking certain duties, bees probably retain more food than when occupied with other duties. A bee's past experience also plays a part in determining the amount of food in her honeystomach when she offers, or begs for, food.

11.13. Free, J. B. (1957). The effect of social facilitation on the ovarial development of bumblebee workers. *Proc. R. ent. Soc.* (*A*), **32**, 182–184.

The extent to which the ovaries of a bumblebee worker develop, and the number of eggs she lays, increases, within certain limits, with the number of other workers present with her.

11.14. Free, J. B. (1958). The defence of bumblebee colonies. *Behaviour*, **12**, 233–242.

The members of a bumblebee colony possess a common odour, and bumblebees are able to recognise intruding bumblebees from other colonies by their scent alone. Under experimental conditions the scent of a strange colony

can become absorbed on to the body surface of a bee, with the result that she is subsequently attacked by members of her own colony.

Large colonies have guards at the entrances of their nests; in smaller colonies, although no guard bees are present, some bees more readily attack intruders than others. The aggressiveness of such bees appears to be related to the relatively high degree of development of their ovaries.

11.15. Simpson, J. (1957). The incidence of swarming among colonies of honeybees in England. *J. agric. Sci.* **49**, 387–393.

Some published figures relating to the incidence of swarming are examined, and records obtained in the routine examinations of colonies in honey-producing apiaries are analysed. It is concluded that in these apiaries between 10 and 40 per cent of colonies would swarm in an average year, if they were given excess of hive space and otherwise left alone. The proportion of colonies which began queen rearing varied from year to year and from one apiary site to another. This variation was presumably due to environmental factors, but it was substantially independent of those factors which determined honey yield. There was no evidence that it was due to the effects of conditions in the years when the queens were reared. After the end of June, at least, the tendency for colonies to rear queens was markedly less with queens of the current year than with queens of the previous year, and was probably also less with queens of the previous year than with still older queens. Occupied queen cells were most frequently observed in colonies in the latter half of May and in June and July. The mean time of queen-rearing varied from year to year. Many colonies which began to rear queens eventually ceased to do so with no other treatment than removal of queen cells. Queen rearing did not begin and end in all colonies at the same time; many colonies began rearing queens after others had stopped.

11.16. Simpson, J. (1957). Observations on colonies of honeybees subjected to treatments designed to induce swarming. *Proc. R. ent. Soc. Lond.* (*A*), **32**, 185–192.

None of the treatments applied were shown to be effective methods of inducing colonies to swarm. Colonies deprived of larval brood showed evidence of a surplus of brood food; those given additional brood to feed were unable to do so effectively, although queen larvae were adequately fed while worker larvae were receiving insufficient food. Brood food surplus is probably not an essential condition for the commencement of swarm preparations, and when acting alone is insufficient to cause such preparations. It was found possible for a colony to swarm without any noticeable reduction in the egg output of its queen and with a large number of empty cells in its combs. Colonies which began rearing young queens frequently destroyed them, sometimes even in the pupal stage; the onset of queen rearing in a colony does not necessarily indicate that it will swarm or even rear queens to maturity.

11.17. Simpson, J. (1958). The factors which cause colonies of *Apis mellifera* to swarm. *Insectes soc.* **5**, 77–95.

This paper consists of a review and discussion of published (and some unpublished) evidence concerning the factors which induce colonies to swarm. It is concluded that most colonies can be induced to swarm by insufficiency of space for bees in their hives, and that in the absence of this factor swarming only occurs in colonies whose queens are unable to supply them with enough queen substance to inhibit them from rearing queens. The amount of queen substance produced by a queen appears to diminish as she becomes older. Queen " supersedure " (the replacement of the queen of a colony without the emergence of a swarm) is also induced by insufficiency of queen substance—see Butler (11.8) above. It seems possible that environmental conditions and the size of the colony decide which process will occur. Large colonies and abundance of nectar and pollen in the field appear to favour swarming rather than supersedure.

The processes which may occur in colonies in the course of preparations to swarm and the factors which may possibly initiate the actual emergence of swarms are also discussed.

Statistics Department

General Papers

12.1. (Page, J. O., Dadd, C. V. T.) & Boyd, D. A. (1957). Cultivation and manuring of potatoes. "Potatoes": Bull. 94, Ministry of Agriculture, Fisheries and Food, pp. 11–21. London: H.M.S.O.

12.2. Yates, F. (1958). "Statistical methods and scientific inference." Comments on D. V. Lindley's review. *Heredity*. (In the press.)

A reply to Lindley's criticisms of Sir Ronald Fisher's new book.

Research Papers

12.3. Leech, F. B. (1958). A national survey of diseases of the dairy cow: the sample of herds. *Vet. Rec.* **70**, 32–34.

A discussion of the factors taken into account when specifying a sample of herds suitable for this survey is followed by a description of the technique of drawing the sample by random selection.

12.4. Mann, H. H. & Boyd, D. A. (1958). Some results of an experiment to compare ley and arable rotations at Woburn. *J. agric. Sci.* (In the press.)

For summary see below No. 15.2.

12.5. (O'Connor, L. K.) & Lipton, S. (1957). Estimation of lactation fat per cent with differing sampling intervals. *Milk Marketing Board report no.* **7**, **1956/7**. Report of the Production Division. (Addendum to Section on National Milk Records, pp. 25–27.)

Estimates of the average lactation fat per cent were obtained using sampling intervals of 7, 14, 28, 42, 56 and 63 days on eighteen lactations, and these estimates were compared with the true actual lactation fat per cent. As expected, the larger the sampling interval, the less accurate the estimates. However, the reduction in accuracy when a 56- or 63-day interval is used instead of a 42-day interval is relatively small. A 28-day interval appears to give a reasonably accurate estimate.

12.6. (Reeve, E. C. R.) & Gower, J. C. (1958). Inbreeding with selection and linkage. 2. Sib-mating. *Ann. hum. Genet.* (In the press.)

The rate of progress to homozygosity of a locus (a, b) linked to a locus (A, B) with recombination frequency (y) is investigated, when a proportion (x) of homozygotes (AA), (BB) survive. The inbreeding system used is full sib-mating, which leads to a 19×19 generation matrix.

12.7. Simpson, H. R. (1957). The effect of sterilized males on a natural tsetse fly population. *Biometrics*. (In the press.)

The use of artificially sterilized males has been suggested as a means of controlling tsetse populations. A mathematical model of a natural tsetse population is set up, and the theoretical effect of the introduction of sterilized males is examined. Numerical results obtained on the Rothamsted computer are presented and discussed.

12.8. Simpson, H. R. (1958). The estimation of linkage on an electronic computer. *Ann. hum. Genet.* (In the press.)

A programme for analysing linkage data from two-generation families on an electronic computer is described. In particular, the coding of the data in a suitable form and the computing time are discussed. Suggestions are made for extending the programme to handle data from three or more generation families.

12.9. YATES, F. & PATTERSON, H. D. (1958). A note on the six-course rotation experiments at Rothamsted and Woburn. *J. agric. Sci.* (In the press.)

The results of an interim examination of the experiments at Rothamsted and Woburn on the effects of nitrogen, phosphate and potash on a six-course rotation of crops are reported.

It has become apparent that the main aim of the experiments, to relate the effects of the fertilizers to weather conditions, is not being fully realized. This is in part a consequence of the design, which has inherently low accuracy and results in low responses to phosphate and potash. In addition, faulty randomization and, at Woburn, fertility irregularities and pest damage have further reduced the accuracy attained.

The faulty randomization also seriously affects the estimates of experimental error given by deviations from smoothed response curves. Alternative estimates of error are provided to overcome this difficulty.

The mean yields and mean standard responses over the period 1931–55 are presented.

There is very little year-to-year variation in the responses to phosphate, but the responses to nitrogen and, for some crops, the responses to potash show sufficient variation to justify further analysis. As a first step the regressions of the responses to nitrogen on winter rainfall and on rainfall during the growing season and, for the root crops only, the regressions on sowing or planting date are briefly considered.

REPORTS

12.10. (BLOOD, J. W., *et al.*), BOYD, D. A., HILLS, M. & SIMPSON, H. R. Preliminary results of the Survey of Fertilizer Practice, 1957.

[Duplicated report.]

Field Experiments Section

GENERAL PAPERS

13.1. DYKE, G. V. (1957). Hand and machine planting of potatoes. *Exp. Husbandry*, 3. (In the press.)

A summary and discussion of Rothamsted experiments.

BOOKS

13.2. GARNER, H. V. & (GARDNER, H. W.) (1957). *The use of lime in British agriculture.* 1st popular edition. London: E. & F. Spon, 15/–.

13.3. GARNER H. V. (1958). *Manures and fertilizers* (Bull. Min. Agric. 36; 10th edition). London: H.M.S.O. (In the press.)

Woburn Experimental Section

15.1. MANN, H. H. & BOYD, D. A. (1958). Some results of an experiment to compare ley and arable rotations at Woburn. *J. agric. Sci.* (In the press.)

The effect of short leys and arable cropping on the yields of the following arable crops has been tested since 1937 at Woburn Experimental Farm, Bedfordshire. The leys were a 3-year grazed ley and 3 years of lucerne cut for hay, and the arable cropping was potatoes, winter cereal and either a 1-year ley or a third tillage crop. The effects of these crop-sequences were measured

by test crops of potatoes and barley, uniformly treated except that 15 tons farmyard manure is applied on one-half of each plot for potatoes.

Without farmyard manure, the yield of potatoes after the grazed ley was higher than after three tillage crops by an average of about 3 tons/acre; after lucerne it was about 2 tons/acre more than after the tillage crops, and after the 1-year ley under 1 ton/acre more. With farmyard manure the benefit from leys was less (about 2 tons/acre for both lucerne and the grazed ley). The average effect of the farmyard manure was about 2·8 tons, except after the grazed ley, where the increase has been only 1·6 tons/acre.

Effects of the previous cropping on the yield of barley were small in the early years of the experiment, but in the last 5 years the yield after ley and lucerne has exceeded that after the tillage crops by about 15 per cent.

Part of the difference in potato yield between the ley and arable sequences can be attributed to the differential incidence of potato-root eelworm, which has reached a high level of infestation on some of the arable plots. Much of the remainder may be ascribed to the low level of basal manuring which has affected the yield of all plots, but particularly those under tillage crops. How far the observed differences can be explained by these considerations remains a matter for speculation, but may to some extent be clarified when further results are obtained from a revised scheme of cropping and manuring.

15.2. Thorold, C. A. (1957). A chlorosis disease of cocoa in the Southern Cameroons. *J. West Afr. Sci. Ass.* **3**, 96–106.

It has not been possible to transmit this chlorosis to healthy plants by grafting nor by mealybugs. A claim that the chlorosis is a nutritional deficiency has not been substantiated. Until the cause is fully understood, there remains some apprehension that the chlorosis is an insidious menace to the cocoa industry of the Southern Cameroons.

Tropical Soils

16.1. Greene, H. (1957). Soil resources: Chap. 7 in *Guide book to research data for arid zone development.* Paris: UNESCO. (*Arid zone research*, **10**, 107–120.)

16.2. Greene, H. (1956). Foreword in *Minerals in Pasture: Deficiencies and excesses in relation to animal health.* (Tech. Commun. 15, Commonwealth Bureau of Animal Nutrition.)

Soil Survey of England and Wales

17.1. Avery, B. W. (1958). A sequence of beechwood soils on the Chiltern hills England. *J. Soil Sci.* **9**. (In the press.)

Under beechwoods, the Chalk and associated superficial deposits of the Chiltern hills give rise to a sequence of soils ranging from rendzina through brown earth (*sol lessivé*) to podzol, closely paralleled in developmental sequences established elsewhere on uniform calcareous materials. The salient features of the genetic soil types represented are described and their evolution discussed in relation to vegetation and site characteristics. On base-deficient soils, mor formation under beech is conditioned by local climatic conditions and management practices, as well as by inherent fertility variations, and is only associated with advanced podzolization on appreciably sandy materials. On silty plateau soils with imperfect drainage, " micro-podzols ", which may be transitory, are formed.

17.2. Osmond, D. A. (1957). Recent advances in pedology. *Sci. Progr.* **45** 292–296.

17.3. Osmond, D. A. & Stephen, I. (1957). Micropedology of some red soils from Cyprus. *J. Soil Sci.* **8**, 19–26.

The micromorphology and mineralogy of terra rossas and rotlehms associated with calcareous sediments and igneous rock material respectively are described. The investigations confirm differences observed in the field and assist in the differentiation and classification of the soils.

General Publications

18.1. Boalch, D. H. *Prints and paintings of British farm livestock 1780–1910: a record of the Rothamsted collection.* Harpenden, Rothamsted Experimental Station, 1958.

Publications of the Rothamsted Experimental Station

(obtainable from the Librarian)

REPORT, ROTHAMSTED EXPERIMENTAL STATION

1908–1914 (annual; 1908 out of print)	1/- each
1915–17, 1918–20 (triennial; 1915–17 out of print)	2/6 each
1921–22, 1923–24, 1925–26, 1927–28 (biennial) ...	
1929–1937 (annual; 1933 out of print)	
1938	Out of print
1939–45 (one issue covering the war years) ...	5/- each
1946, 1947	3/- each
1948, 1949	5/- each
1950–1954 (annual)	7/6 each
1955	8/6
1956, 1957	10/- each

ROTHAMSTED MEMOIRS ON AGRICULTURAL SCIENCE

1 (1847–63)—**8** (1896–1912), 1863–1914 ...	Out of print
9 (1909–16)—**11** (1920–22), 1919–24	32/6 each
12 (1922–25), 1926	33/6
13 (1925–27), 1928	Out of print
14 (1928–30), 1930	35/-
15 (1922–31)—**23** (1939–40), 1932–40	36/- each
24 (1940–41)—**31** (1952–53), 1947–56	60/- each
32 (1953–55), **33** (1955–56)	80/- each

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ROTHAMSTED MEMOIRS, FROM THE " PHILOSOPHICAL TRANSACTIONS "

1 (1861–89), 1893	Out of print
2 (1880–1900), 1893	
3 (1859–83), 1893	
4 (1914–34), 1934	20/-

(These are published in quarto.)

ROTHAMSTED CONFERENCE REPORTS: being papers by practical farmers and scientific experts.

† *The manuring of potatoes.* (1925; 1/6.)
* (1) *The growing of lucerne.* (1926.)
* (2) *The culture and manuring of fodder crops.* (1926.)
* (3) *Green manuring.* . . . (1927.)
(4) *The culture and manuring of sugar beet.* (1927; 2/6.)
(5) *The art and science of cultivation.* (1927; 2/-.)
(6) *Power for cultivation and haulage on the farm.* (1928; 2/6.)
(7) *Malting barley.* (1928; 2/6.)
* (8) *Recent changes in systems of husbandry in England.* (1929.)

† Unnumbered. * Out of Print.

(9) *The Hertfordshire agricultural situation: Can it be improved?* (1929; 2/-.)
(10) *The growth of cheaper winter food for live stock.* (1930; 2/6.)
(11) *The making of new grassland: experiences of practical farmers.* (1931; 2/6.)
(12) *The place and management of sheep in modern farming.* (1931; 1/6.)
(13) *The technique of field experiments.* (1931; 1/6.)
(14) *Mechanization and British agriculture.* (1932; 2/6.)
(15) *Recent developments in market gardening.* (1932; 2/-.)
(16) *Problems of potato growing.* (1934; 2/-.)
(17) *Modern changes in the treatment of light soil.* (1934; 2/-.)
*(18) *Brood diseases of bees.* (1934.)
(19) *The production of pigs for bacon.* (1935; 1/6.)
*(20) *The cause and control of swarming bees.* (1935.)
(21) *The use of electricity in agriculture.* (1936; 2/-.)
(22) *Diseases of bees.* (1936; 1/6.)

Numbers 1–20 were also published in four bound volumes:

Volume 1 (*Conferences* 1–5)	out of print.
Volume 2 (*Conferences* 6–10)	10/-.
Volume 3 (*Conferences* 11–15)	10/-.
Volume 4 (*Conferences* 16–20)	out of print.

GUIDE TO THE EXPERIMENTAL FARMS. (1954; 6*d.*)
INVESTIGATIONS IN THE LABORATORIES. (1957; 6*d.*)
*ROTHAMSTED, 1843–1943: the work and history of the departments. (1943.)

ROTHAMSTED EXPERIMENTAL STATION LIBRARY

Catalogue of the printed books on agriculture published between 1471 and 1840, by Mary S. Aslin. (Rothamsted, 1926.)*
—*Second Edition.* (Rothamsted, 1940. Cloth, 15/-; paper, 12/-.)
—*Supplement* . . . List of additions since 1940. (Rothamsted, 1949; paper, 2/6.)
Catalogue of serial publications in the Library, 1953. Edited by D. H. Boalch. (Rothamsted, 1954; 17/6.)
Catalogue of serial publications in the West Building Library at Rothamsted (Entomology, Insecticides, Mycology), March, 1956. Edited by D. H. Boalch. (Rothamsted, 1956; mimeographed; 2/-.)
The Manor of Rothamsted: [a history and guide], by D. H. Boalch. (Rothamsted, 1953; 7/6.)
Prints and paintings of British farm livestock 1780–1910: a record of the Rothamsted Collection, by D. H. Boalch. (Rothamsted, 1958; one guinea.)

* Out of Print.

Books by Present and Past Members of the Rothamsted Staff

*1911 HALL, Sir A. D. & RUSSELL, Sir E. J. A report on the agriculture and soils of Kent, Surrey and Sussex. London: H.M.S.O.

*1913 RUSSELL, Sir E. J. *The fertility of the soil.* Cambridge University Press.

*1917 HALL, Sir A. D. *The book of the Rothamsted experiments.* 2nd edition. London: John Murray.

*1917 RUSSELL, Sir E. J. *Manuring for higher crop production.* Cambridge University Press.

*1920 BRENCHLEY, Winifred E. *Weeds of farmland.* London: Longmans, Green & Co.

*1922 GREY, Edwin. *Reminiscences, tales and anecdotes of the laboratories, staff and experimental fields, 1872–1922.* Rothamsted Experimental Station.

*1923 RUSSELL, Sir E. J. *et al. The micro-organisms of soil,* by E. J. Russell and the staff of the Rothamsted Experimental Station. London: Longmans, Green & Co.

*1924 BRENCHLEY, Winifred E. *Manuring of grassland for hay.* London: Longmans, Green & Co.

*1924 RUSSELL, Sir E. J. *Plant nutrition and crop production,* being the Hitchcock Lectures, 1924. University of California Press and Cambridge University Press.

*1925 DAVIDSON, J. *A list of British aphides. . . .* London: Longmans, Green & Co.

*1927 BRENCHLEY, Winifred E. *Inorganic plant poisons and stimulants.* 2nd edition, revised and enlarged. Cambridge University Press.

*1929 HALL, Sir A. D. *The book of the tulip.* London: Martin Hopkinson.

*1931 KEEN, Sir B. A. *The physical properties of the soil.* London: Longmans, Green & Co.

*1932 CUTLER, D. Ward. *Evolution, heredity and variation.* London: Christophers.

*1933 HALL, Sir A. D. & CRANE, M. B. *The apple.* London: Martin Hopkinson.

*1933 RUSSELL, Sir E. J. *The farm and the nation.* London: George Allen and Unwin Ltd.

*1935 CUTLER, D. Ward & CRUMP, Lettice M. *Problems in soil microbiology.* London: Longmans, Green & Co.

*1935 GREY, Edwin. *Cottage life in a Hertfordshire village.* St. Albans: Fisher Knight & Co.

* Out of Print.

*1936 Russell, Sir E. J. & Voelcker, J. A. *Fifty years of field experiments at the Woburn Experimental Station.* With a statistical report by W. G. Cochran. London: Longmans, Green & Co.

*1939 Nicol, Hugh. *Microbes by the million.* Harmondsworth: Penguin Books Ltd.

*1939 Russell, Sir E. J. *Artificial fertilizers in modern agriculture.* Ministry of Agriculture and Fisheries Bulletin no. 28, [3rd edition]. London: H.M. Stationery Office.

*1939 Russell, Sir E. J. *Report on the work of the Imperial Council of Agricultural Research in applying science to crop production in India.* Reprinted. Simla: Government of India Press.

1940 Nicol, Hugh. *Plant growth substances.* 2nd edition. London: Leonard Hill, 3/6.

1941 Russell, Sir E. J. *English farming.* London: William Collins, Sons & Co., 5/-.

*1943 Nicol, Hugh. *Biological control of insects.* Harmondsworth: Penguin Books Ltd.

1944 Garrett, S. D. *Root disease fungi.* Waltham, Mass.: Chronica Botanica Co., $4.50.

1944 Hall, Sir A. D. *The feeding of crops and stock.* Parts 1 and 2 revised by Sir W. G. Ogg. 3rd edition. London: John Murray, 12/-.

1946 Russell, Sir E. J. *British agricultural research: Rothamsted.* Revised edition. London: published for the British Council by Longmans, Green & Co., 1/6.—Available from the Librarian, Rothamsted Experimental Station, as also are a Spanish translation (new impression, 1947, 1/-) and a Portuguese translation (1942, 1/-).

1948 Butler, C. G. *The importance of bees in orchards.* Ministry of Agriculture Bulletin no. 328. London: H.M. Stationery Office, 9*d*.

1948 Fisher, Sir R. A. *Statistical methods for research workers.* 10th edition. Edinburgh: Oliver & Boyd, 16/-.

1948 Garner, H. V. *& others. Profit from fertilizers.* 3rd edition. London: Crosby Lockwood & Son, Ltd., 15/-.

1948 Russell, Sir E. J. *A student's book on soils and manures.* 4th edition. Cambridge University Press, 8/6.

1948 Tracey, M. V. *Proteins and life.* London: Pilot Press; reprinted by Chapman & Hall Ltd., 10/6.

1948–56 Barnes, H. F. *Gall midges of economic importance.* Volumes 1–7. London: Crosby Lockwood & Son, Ltd. Vol. 1, 12/6; Vols. 2–6, 15/-; Vol. 7, 21/-. One more volume will complete the work.

1949 Butler, C. G. *Beehives.* Ministry of Agriculture Bulletin no. 144. London: H.M. Stationery Office, 9*d*.

1949 Butler, C. G. *The honeybee: an introduction to her sense-physiology and behaviour.* London: Oxford University Press, 10/6.

* Out of Print.

1949 GOODEY, T. *Laboratory methods for work with plant and soil nematodes.* Ministry of Agriculture Technical Bulletin no. 2. London: H.M. Stationery Office, 9*d*.

1949 HALL, Sir A. D. *The soil: an introduction to the scientific study of the growth of crops.* 5th edition. London: John Murray, 9/-.

1949 LONG, H. C. & BRENCHLEY, Winifred E. *The suppression of weeds by fertilizers and chemicals.* 3rd and enlarged edition. London: Crosby Lockwood & Co., 7/6.

1949. PIRIE, N. W. *The nature of the bacterial surface.* Edited by A. A. Miles & N. W. Pirie. Oxford: Blackwell Scientific Publications, 15/-.

1950 BAWDEN, F. C. *Plant diseases.* Revised edition. London: Thomas Nelson & Sons Ltd., 8/6.

1950 BAWDEN, F. C. *Plant viruses and virus diseases.* 3rd edition. Waltham, Mass.: Chronica Botanica Co., $4.75.

1950 RUSSELL, Sir E. J. *Lessons on soil.* 2nd ed. Cambridge University Press, 7/6.

1950 RUSSELL, Sir E. J. *Soil conditions and plant growth.* 8th edition, recast and rewritten by E. Walter Russell. London: Longmans, Green & Co., 35/-.

1951 GOODEY, T. *Soil and freshwater nematodes.* London: Methuen & Co., Ltd., 45/-.

1951 FRANKLIN, Mary T. *The cyst-forming species of Heterodera.* Farnham Royal: Commonwealth Agricultural Bureaux, 18/6.

1951 PIRIE, N. W. *Four thousand million mouths.* Edited by F. Le Gros Clark & N. W. Pirie. Oxford University Press, 12/6.

1953 BOALCH, D. H. *The manor of Rothamsted.* Harpenden: Rothamsted Experimental Station, 7/6.

1953 FISHER, Sir R. A. & YATES, F. *Statistical tables for biological, agricultural and medical research.* 4th edition. Edinburgh: Oliver & Boyd, 21/-.

1953 RIBBANDS, C. R. *The behaviour and social life of honeybees.* London: Bee Research Association Ltd., 21/-.

1953 YATES, F. *Sampling methods for censuses and surveys.* 2nd edition. London: Griffin, 38/-.

1954 BOALCH, D. H., *ed. Catalogue of serial publications in the library of Rothamsted Experimental Station, 1953.* Harpenden: Rothamsted Experimental Station, 17/6.

1954 BUTLER, C. G. *The world of the honeybee.* (New Naturalist series.) London: Collins, 21/-.

1954 GOLDSCHMIDT, V. M. *Geochemistry.* Edited by A. Muir. Oxford: Clarendon Press, 63/-.

1954 RUSSELL, Sir E. J. *World population and world food supplies.* London: Allen & Unwin Ltd., 50/-.

1954 TRACEY, M. V. *Principles of biochemistry: A biological approach.* London: Sir Isaac Pitman & Sons, Ltd., 20/-.

1955 HALL, Sir A. D. *Fertilizers and manures.* 5th edition. London: John Murray, 10/6.

1955 PENMAN, H. L. *Humidity.* London: Institute of Physics, 5/-.

1955 PIRIE, N. W. *The numbers of man and animals.* Edited by J. B. Cragg & N. W. Pirie. Edinburgh: Oliver & Boyd, 15/-.

1955–56 TRACEY, M. V. *Modern methods of plant analysis.* Edited by K. Paech & M. V. Tracey. Berlin: Springer-Verlag, 4 Volumes, £43 16*s.* 6*d.*

1957 BROADBENT, L. *Investigation of virus diseases of brassica crops.* (A.R.C. report series, no. 14.) Cambridge: University Press, 15/-.

1957 BUTLER, C. G. *Beekeeping.* Bulletin Min. Agric. Fish. & Food, 9. [9th edition.] London: H.M. Stationery Office, 2/-.

1957 GARNER, H. V. *The use of lime in British agriculture.* By H. W. Gardner & H. V. Garner. 1st popular edition. London: E. & F. N. Spon Ltd., 15/-. [First edition, 1953.]

1957 RUSSELL, Sir E. J. *The world of the soil.* (New Naturalist Series.) London: Collins, 25/-.

1958 BOALCH, D. H. *Prints and paintings of British farm livestock 1780–1910: a record of the Rothamsted Collection.* Harpenden: Rothamsted Experimental Station, 21/-.

FIFTY-YEAR INDEX

TO THE

ROTHAMSTED ANNUAL REPORT

(1908–57)

For fifty years the work of Rothamsted has been described in the *Rothamsted Annual Report.* The first *Report* (for 1908) was a pamphlet sixteen pages in length. Subsequent issues have steadily increased in size, keeping pace with the expansion of Rothamsted itself, until today the *Report* cannot be kept down much below 300 pages.

How were the results of the Rothamsted experiments communicated to the public before the *Report* was started?

The earliest published account of the work at Rothamsted appeared over Sir John Lawes's signature in *The Gardener's Chronicle and Agricultural Gazette,* 14 June 1845 (pp. 406–407).

In July 1855—the month in which the Testimonial Laboratory, presented to Lawes by a group of Hertfordshire farmers, was opened—the first independent report of the Rothamsted experiments, a pamphlet of four pages, was issued under the title *Rothamsted Farm.*

From 1862 to 1901 *Memoranda of the plan and results of the Rothamsted field experiments* were published under slightly varying titles—annually from 1869 to 1901. This publication was superseded by *Plans and summary tables, arranged for reference in the fields,* which had started in 1896 and continued until 1905.

A *Guide to the experimental plots* was issued in 1906, and the first *Annual Report* (for 1908, published in 1909) was designed partly as a supplement to the *Guide.*

For the first seven years, as also since 1946, the *Report* was published annually; during the intervening period a number of issues covering two or more years appeared.

Fifty-Year Index to the Rothamsted Annual Report

(1908–57)

Note: This is *not* a full technical index. It records only review articles and summaries of experimental results, buildings erected and land acquired, chairmen of the Lawes Agricultural Trust Committee, Directors and Heads of Departments of Rothamsted Experimental Station, and a few miscellanea.

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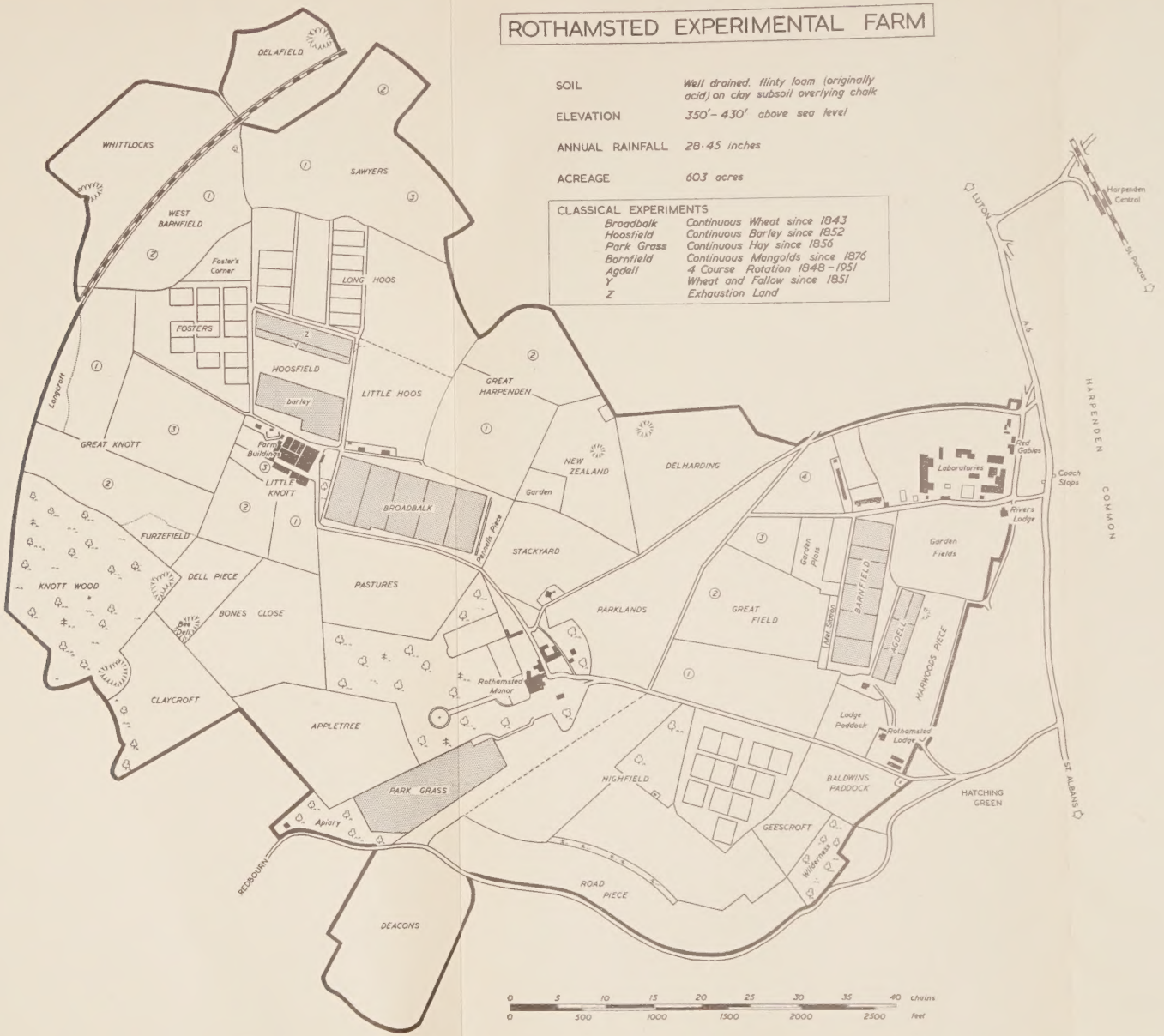
ROTHAMSTED EXPERIMENTAL FARM
SOIL
Well drained. flinty loam (originally acid) on clay subsoil overlying chalk
ELEVATION
350' – 430' above sea level
ANNUAL RAINFALL
28·45 inches
ACREAGE
603 acres
CLASSICAL EXPERIMENTS
Broadbalk Continuous Wheat since 1843
Hoosfield Continuous Barley since 1852
Park Grass Continuous Hay since 1856
Barnfield Continuous Mangolds since 1876
Agdell 4 Course Rotation 1848 – 1951
Y Wheat and Fallow since 1851
Z Exhaustion Land
DELAFIELD
WHITTLOCKS
SAWYERS
WEST BARNFIELD
Foster's Corner
LONG HOOS
FOSTERS
HOOSFIELD
barley
LITTLE HOOS
GREAT HARPENDEN
Longcroft
GREAT KNOTT
Farm Buildings
LITTLE KNOTT
NEW ZEALAND
DELHARDING
Garden
BROADBALK
Pinetells Piece
STACKYARD
FURZEFIELD
KNOTT WOOD
DELL PIECE
BONES CLOSE
PASTURES
Bee Dell
PARKLANDS
GREAT FIELD
Rothamsted Manor
CLAYCROFT
APPLETREE
PARK GRASS
Apiary
HIGHFIELD
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Wilderness
ROAD PIECE
DEACONS
MEDBOURN
LUTON
A.6
Harpenden Central
St. Pancras
HARPENDEN COMMON
Red Gables
Laboratories
Coach Stops
Rivers Lodge
Garden Plots
Garden Fields
BARNFIELD
Hall Sheds
AGDELL
HARWOODS PIECE
Lodge Paddock
Rothamsted Lodge
BALDWINS PADDOCK
HATCHING GREEN
ST. ALBANS
0 5 10 15 20 25 30 35 40 chains
0 500 1000 1500 2000 2500 feet
1958